ECOLOGICAL STUDIES OF SHIPWORM ATTACK ON WOOD IN THE SEA WATER LOG STORAGE SITE

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Contents

Introduction

The wood-boring bivalve molluscs of the family Teredinidae, commonly called " shipworm "[1), have been well known to man since antiquity.

Shipworms are the most specialized molluscan borers adapted for boring into wood. The natural habitats of the shipworms are mangrove roots, drifting timber and other cellulosic materials in the sea. Shipworms accordingly play an important ecological role in the reduction of water-borne wood into its constituent elements. On the other hand, shipworms are serious pests of wooden ships, wooden coastal structures and logs stored in the sea, and they cause a lot of economic damage.

Shipworms settle on the surface of wood during free-swimming period, and they subsequently begin to penetrate into wood. After initial penetration, they spend the rest of their lives in the wood substrate and continue to burrow as long as they live. The tunnel elongates with the growth of shipworm that fills entire length of the tunnel, and the animal seals off the anterior end with a calcareous lining when no more space is available for it. However, the initial entrance hole is generally very small, and is only slightly enlarged throughout the life of the animal. Consequently, the damage is not readily detected until the wood is nearly or completely riddled by shipworms.

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1) The terms of pileworm, teredo, teredinid, and teredine borer are applicable to meaning " shipworm ".

The body of an adult shipworm is extremely elongated and long worm-like. The shell is reduced to 2 small anterior valves which are nearly hemispherical, with a deep right-angled notch in the ventral half of the anterior margin. The valve is the mechanical tool for rasping of wood. Most of the vital organs of shipworms are located posteriorly to the valves and are enclosed by mantle. The siphons are relatively short, and are extended from the minute opening at the surface of wood into the surrounding water for respiration, feeding and excretion. When shipworms are disturbed, the siphons are retracted within the tunnel. Simultaneously, the surface opening is plugged by the pair of pallets which are highly specialized organs to close the burrow entrance.

Shipworms definely ingest the rasped fine particles of wood: the stomach is provided with a caecum for storing fine particles, though the extent of dependence on wood as food probably varies with species.

The shipworms appeared on the earth relatively early, and they are found in fossil wood in marine or brackish water sediments. The animal first appeared in the Lower Cretaceous according to Hatai (1951). d'Orbigny (1849), Whitfield and Hovey (1906), Moll (1942) and others found them among fossilized samples in the Jurassic. Therefore, it can be easily presumable that the attempts to prevent shipworm attack began in the ancient time when man first used wooden rafts and boats.

The old Greek, Aristophanes (448-380BC) and Theophrastus (372?-287BC) well documented the dread of the destructive power of the shipworms. The old Roman, Ovid (43BC-17AD) and Pliny (23-79AD) also left the similar records. The log-books of the early famous navigators such as Drake and Cook evidenced that they feared shipworm attack on their vessels as much as the tempest or incurable infectious diseases. Many of the explorers of the Age of Discovery lost their vessels during the voyage because the vessels were weakened by shipworm attack so severely that they could not endure the heavy tempest. It is well known that Columbus lost all his vessels on his 4th voyage to the New World and had to be rescued from Jamica (Morison, 1965). These early navigators possibly contributed to the wide distribution of shipworms in the world since industrial status and maritime trade rose at that time.

At last, the catastrophic ravage occurred in the Netherlands in 1730. Shipworms invaded invisibly the wooden-faced dykes which protected the reclaimed lowlands, and the country suffered widespread inundation. This disaster stimulated scientists to study shipworms from various points of view. Scientific interest in the shipworms naturally started from attempts to discover effective methods for preventing their attack on wooden ships and structures in the sea. In 1733, Sellius published the monograph on the shipworms, and proved that shipworms belong to phylum Mollusca. He also recommended " creosote " for the protection of timber in marine use. Creosote is still widely employed in the world for the purpose.

More recently, the unforseen ravages were caused by the introduction of Teredo navalis Linnaeus newly into San Francisco Bay, California, U.S.A. in 1914. The San Francisco Bay Marine Piling Committee was established in 1921 to investigate comprehensively the marine borer problem. Under the support of the committee, many papers were separately published. Hill and Kofoid (1927) afterwards summarized the papers in the book entitled " Marine borers and their relation to marine constructions on the Pacific coast " as the final report of the committee.

In addition, test board operation supported by the U.S. Navy was initiated in 1920's under the directorship of W.F. Clapp and the National Research Council. Test boards removed from various parts of the world were examined at W.F.Clapp Laboratories by the mid 1950's. Annual reports of W.F.Clapp Laboratories provided the information on species present, settling season and abundance of borers for each test locality. Their test board operation covered the tests at Sasebo and Yokosuka in Japan.

A little earlier, Atwood and Johnson (1924), together with associates, compiled a book, and made many significant contributions to the knowledge of marine borer problem.

Moreover, the scientific interest in marine borer attack on wood was intensely stimulated about the time of World War II in several countries including Japan.

In Japan, the prevention of shipworm attack became a matter of importance with the increased use of wooden ships during World War II, though investigations on the Teredinidae had already begun in the early 20th century. The 22nd Special Committee for the prevention of marine borer attack was organized by the Japan Society for the Promotion of Science in November, 1943 to accelerate the pace of the research on the problem. The results of the research of this committee were published in the book edited by Okada (1958), " Attack on wooden ships and timbers by marine borers and its prevention ". Unfortunately, the Society did not continue support of the committee after the war. Since that time, only a few papers which relate to the Teredinidae have appeared.

Before World War II, Clessin (1893), Nakazawa (1915), Kamiya (1918), Roch and Moll (1929), Minobe (1930), Kuronuma (1931), Miyazaki (1935) and others were concerned with the Japanese shipworms.

The interest was mainly centered on marine wooden constructions and ships before and during World War II. As mentioned above, a lot of work has been done to eradicate shipworms or to prevent their attacks. However, the shipworms have been one of the most serious marine pests in the world domestically and internationally for the last few hundred years. The shipworms are distributed all over the world and their distribution varies with oceanographic environmental factors, i.e. water temperature, salinity, food supply, and other ecological factors based on latitude, tidal current, etc. In this sense, it is very important to investigate the problem on a world-wide basis[1].

1) Working group named " Wood in marine environment " is organized by O.E.C.D. to investigate the problem internationally.

Wood is generally vulnerable to shipworm attack. On the other hand, a few tropical hardwoods are naturally resistant to the attack of shipworm[1]. However, there is not sufficient supply of these hardwoods for the world's marine wooden construction needs. In spite of the fact that concrete and steel installations are increasingly taking place of wooden structures in the sea, wood is still widely used.

Therefore, we are obliged to pay consideration to preserving timber in the sea by chemical treatment or physical barriers. Many preserving and protecting attempts have been examined by early workers. Contrary to our expectation, the results of these attempts are unsatisfactory in terms of reliability, cost and risks.

In present-day Japan, the shipworm problem is characterized by the fact that the more attention should be paid to the damage of imported logs stored in the sea rather than to marine wooden installations or ships because of the increase of replacing them by concrete, steel and plastic materials. Over 60 % of the total supply of wood in Japan annually depends on the imported logs from North America, U.S.S.R., Southeast Asia, and other parts of the world. The imported logs are generally stored in the sea water log storage areas along the coasts of Japan. During this sea water storage, the logs are unprotectedly exposed to marine borers, especially to shipworms.

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1) Four softwood species (*Pinus densiflora* Sieb. et Zucc., *Pinus sylvestris* Linnaeus, *Tsuga heterophylla* Sargent and *Pseudotsuga menziesii* (Mirb.) Franco) used in this study are well known to be non-resistant against shipworm attack.

Only a few papers have so far discussed the problem involved in protecting logs stored in the sea (Trussell et al., 1956; Mawatari, 1958 and 1959).

The first step to restrain the shipworm attack on timber and logs in sea water is to supply basic biological and ecological informations.

This dissertation is divided into 5 parts. The 1st part is related to the distribution of the shipworms along the coasts of Japan with a brief historical survey of the literature on the Japanese shipworms. The 2nd part refers to the season of settlement of shipworms at various localities in Japan, which would suggest the reasonable operation of log storage area and indicate when and how long the logs can be stored in sea water without any attack of shipworms. The 3rd part discusses the pattern of vertical settlement of shipworms in the sea water log storage site. The 4th part is concerned with the rates of growth of shipworms, *Teredo navalis* Linnaeus, the commonest species in Japanese waters as well as in the world. In the 5th part, the rate of shipworm attack on wood is discussed as it is directly related to the damage of wood including the logs stored in the sea.

I. Distribution of the Shipworms along the Coasts of Japan

Clessin (1893) is the first investigator to describe a Japanese shipworm. Roch and Moll (1929), Kuronuma (1931), and others reported on the shipworms from Japan before World War II. More recently, Taki and Habe (1945, 1958), and Habe (1952, 1953, 1977) described the classification of the Japanese shipworms according to their own systematics. However, no taxonomist has followed their systematics.

Turner (1966) proposed a new plausible classification based on the anatomy of the animals, and the structure and variation of the pallets. She dealt with the anatomy of 34 species covering 14 genera, and showed the anatomical differences among genera. She reviewed the early works that have been done on the systematics, geographic distribution and biology, and made a catalogue of all named forms with illustrations of the type specimens.

This part includes the review of the early works dealing with the classification of shipworms found in Japan according to Turner's systematics (1966, 1971), and discuss the present results on the distribution of the shipworms along the coasts of Japan together with the locality records in the literature.

I-1. Historical Survey on the all named Forms of Japanese Shipworms

Because of a number of all named Japanese forms in the early papers are definitely synonymous of known species according to the new systematics (Turner, 1966), they should be briefly reviewed before going to discussing the classification and distribution of Japanese shipworms so that one can avoid confusing species.

With the advance of investigations, the number of species that have appeared in papers increased, and amounted to about 40 up to the present.

Clessin (1893) listed only one species from Japan: Teredo japonica Clessin as a new species. Roch and Moll (1929) described 6 new species, including Teredo yatsui Moll, Teredo takanoshimensis Roch, Bankia kuronunii Roch, Bankia kingyokuensis Roch, Nausitora orientalis Roch, and Nausitora kamiyai Roch. Three new species were added to the list by Kuronuma (1931) who identified the specimens from Kusatsu, Hiroshima Pref., Tateyama Bay, Chiba Pref., and Kanazawa, Kanagawa Pref.: Teredo hibicola Kuronuma, Teredo tateyamensis Kuronuma, and Bankia nakazawai Kuronuma. Moll (1941) reported Bankia setacea (Tryon) from Sakhalin[1] as a new record when he described on the shipworms from Japan. Taki and Habe who took charge of the classification of molluscan wood borers for the foregoing 22nd Special Committee identified species collected from various localities. They (1945, 1958) and Habe (1952, 1953) added 24 new specific names to the catologue of the Japanese shipworms.

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1) Sakhalin was a part of Japan at that time.

More recently, Mawatari and Kitamura (1960, 1961) enumerated 12 species collected along the coasts of Kagoshima Pref., with 2 of them described as new. Habe (1977) listed Bankia fimbriatula Moll and Roch with a brief description. In addition, W.F.Clapp Laboratories' reports (e.g. 1950, 1956, 1960) showed the occurrence of shipworms at Yokosuka, Kanagawa Pref. and Sasebo, Nagasaki Pref.

Specific names recorded in Japan are shown in Table 1 with authors' names and date. The number of specific names that appeared in the literature amounts to 44.

According to Turner's catalogue (1966) and identification key (1971), 25 species can be recognized in Japan today. Two of them are still questionable because of the lack of sufficient description and illustrations of Japanese materials: Teredora aurita (Hedley) and Zachsia zenkewitschi Bulatoff and Rjabtschikoff. Moreover, Bankia inoi Habe and and Bactronophorus philippinensis (Bartsch) are nude names.

Moll (1941) considered Lyrodus (Teredo) yatsui Moll and Lyrodus (Teredo) hibicola Kuronuma as synonyms of Lyrodus siamensis Bartsch (= a synonym of Lyrodus pedicellatus (Quatrefages) after Turner, 1966), and also Bankia nakazawai Kuronuma as identical to Bankia kuronunii Roch (= a synonym of Bankia carinata (Gray) after Turner, 1966). Taki and Habe (1945) regarded Bankia kuronunii Roch and Bankia nakazawai Kuronuma as synonyms of Bankia oryzaformis Sivickis (= a synonym of Bankia carinata (Gray) after Turner, 1966). They (1958) also included Nausitora kamiyai Roch in a synonymous form of Bankia (Nausitora) orientalis Roch, but both are young *Bankia carinata* (Gray). On the basis of growth stages in the pallets of *Bankia carinata* (Gray) (Turner, 1966), these 2 species are surely the same.

Clench and Turner (1946), Taki and Habe (1945), and Habe (1952) regarded *Bankia kingyokuensis* Roch as a synonym of *Bankia bipalmulata* (Lamarck), but Turner (1966) who examined the type specimen afterwards confirmed that *Bankia kingyokuensis* is a synonym of *Bankia bipennata* (Turton).

Taki and Habe (1945) listed *Teredora aurita* (Hedley), and Habe (1952) considered *Teredo gazettae* Roch (error for *gazellae* Roch) and *Teredo diederichseni* Roch as synonyms of *Teredora aurita* (Hedley). These are all synonymous forms of *Teredora princesae* (Sivickis) according to Turner (1966). However, Hedley (1899) described *Nausitora aurita* Hedley on the basis of shells only, and Habe (1952) gave no description of it. Likewise, *Bactronophorus philippinensis* (Bartsch) (Taki and Habe, 1945) and *Bankia inoi* Habe (Habe, 1952) were mentioned without any description and illustration. Habe (1952) later gave an illustration of the former species. From his illustration this is distinctly *Bactronophorus thoracites* (Gould). The pallets of *Zachsia zenkewitschi* Bulatoff and Rjabtschikoff measured 1.8 mm in length for specimens from Matsunaga Bay, Hiroshima Pref. (Taki and Habe, 1958). No further details was given. This might be a malformed or stenomorphic form of a known species.

Bankia osumiensis Mawatari and Kitamura (Mawatari and Kitamura, 1960) differs obviously from *Bankia setacea* (Tryon) and *Bankia bipalmulata* (Lamarck) since serrations of

Table 1. Specific names of shipworms recorded in Japan with authors' names and date.

Specific name	Authors' names and date
1. Teredo japonica Clessin	Clessin (1893)
2. Teredo takanoshimensis Roch	Roch and Moll (1929)
3. Teredo yatsui Moll	
4. Nausitora orientalis Roch	
5. Nausitora kamiyai Roch	
6. Bankia kuronunii Roch	
7. Bankia kingyokuensis Roch	
8. Teredo hibicola Kuronuma	Kuronuma (1931)
9. Teredo tateyamensis Kuronuma	
10. Bankia nakazawai Kuronuma	
11. Bankia setacea (Tryon)	Moll (1941)
12. Teredo parksi Bartsch	Taki and Habe (1945)
13. Teredo taiwanensis Taki and Habe	
14. Psiloteredo pentagonalis Taki and Habe	
15. Psiloteredo hydei Sivickis	
16. Psiloteredo kirai Taki and Habe	
17. Teredora aurita (Hedley)	
18. Kuphus smithi (Bartsch)	
19. Kuphus matocotana (Bartsch)	
20. Kuphus kiiensis Taki and Habe	
21. Kuphus teredoides Taki and Habe	
22. Bactronophorus philippinensis (Bartsch) (nude name)	
23. Zachsia zenkewitschi Bulatoff and Rjabtschikoff	
24. Bankia rubra Sivickis	
25. Bankia komai Taki and Habe	
26. Bankia oryzaformis Sivickis	
27. Bankia carinata (Gray)	
28. Bankia tenuis Sivickis	
29. Teredo matsushimaensis Hatai (fossil record)	Hatai (1951)

Table 1 continued.

30. *Teredo massa* Lamy 31. *Teredo diegensis* Bartsch	Clapp Report (1950)
32. *Teredora sparki* (Roch) (error for *sparcki* Roch) 33. *Bankia inoi* Habe (nude name) 34. *Psiloteredo yakushimae* Habe 35. *Dicyathifer polythalamia* (Linnaeus) 36. *Coeloteredo mindanensis* Bartsch	Habe (1952)
37. *Glumebra shionomisakiensis* Habe	Habe (1953)
38. *Bankia orientalis* (Roch)	Taki and Habe (1958)
39. *Bankia osumiensis* Mawatari and Kitamura 40. *Psiloteredo septa* Mawatari and Kitamura 41. *Teredo radclifei* Bartsch	Mawatari and Kitamura (1960)
42. *Teredo milleri* Dall, Bartsch and Rehder	Mawatari and Kitamura (1961)
43. *Bankia campanellata* Moll and Roch	Tsunoda (1977)
44. *Bankia fimbriatula* Moll and Roch	Habe (1977)

cones are distinct at least on the outer margin. This is probably a synonym of *Bankia johnsoni* Bartsch, although it is not definite until the type specimen is examined.

Teredo matsushimaensis Hatai was found among fossil samples extracted from Lower Cretaceous rocks in Miyako, Iwate Pref., and named on the basis of shells and tubes only (Hatai, 1951).

Table 2 shows the catalogue of the Japanese shipworms arranged according to the new Turner's systematics that is widely accepted in the world at present: 4 species each in *Teredo* and *Lyrodus*, 9 in *Bankia*, 2 in *Teredothyra* and 1 each in Kuphus, Nototeredo, Uperotus, Teredora, Zachsia and Bactronophorus. It seems that 25 species are recognized in Japan. However, it is worthy to be considered if species are found in test panels or not, for some species were collected undoubtedly from drift timbers and the riddled hull of wooden ship. Because the adults of shipworms can survive a wide range of salinities and water temperatures, the records which are not based on the test panel method would become invalid. It means that newly introduced species by drift timber into Japanese waters can survive and occasionally reproduce when the environmental conditions become suitable for fertilization and spawning of the offsprings. Therefore, the test panel method must be used to ascertain the existence of shipworm species at a given locality.

Only 10 species of the shipworms listed in Table 2: Teredo navalis Linnaeus, Teredo furcifera von Martens, Teredo triangularis Edmondson, Lyrodus pedicellatus (Quatrefages), Lyrodus takanoshimensis (Roch), Lyrodus massa (Lamy), Bankia carinata (Gray), Bankia bipalmulata (Lamarck), Bankia campanellata Moll and Roch, Teredothyra smithi (Bartsch) were certainly found in test panels. Further investigation would consequently be required for other species.

Table 2. Japanese shipworms with synonyms found in the early works.

Specific name	Synonyms
1. Teredo navalis Linnaeus	Teredo japonica Clessin
2. Teredo triangularis Edmondson	Kuphus teredoides Taki and Habe*

Table 2 continued.

3. *Teredo mindanensis* Bartsch	*Coeloteredo mindanensis* Bartsch
4. *Teredo furcifera* von Martens	*Teredo parksi* Bartsch
5. *Lyrodus pedicellatus* (Quatrefages)	*Teredo yatsui* Moll *Teredo hibicola* Kuronuma *Teredo tateyamensis* Kuronuma *Teredo taiwanensis* Taki and Habe *Teredo diegensis* Bartsch
6. *Lyrodus takanoshimensis* (Roch)	*Teredo takanoshimensis* Roch
7. *Lyrodus affinis* (Deshayes)	*Teredo milleri* Dall, Bartsch and Rehder
8. *Lyrodus massa* (Lamy)	*Teredo massa* Lamy
9. *Bankia carinata* (Gray)	*Nausitora orientalis* Roch* *Nausitora kamiyai* Roch* *Bankia nakazawai* Kuronuma *Bankia oryzaformis* Sivickis *Bankia kuronunii* Roch *Bankia orientalis* (Roch)
10. *Bankia bipalmulata* (Lamarck)	*Bankia rubra* Sivickis
11. *Bankia bipennata* (Turton)	*Bankia kingyokuensis* Roch
12. *Bankia setacea* (Gray)	
13. *Bankia rochi* (Moll)	*Bankia komaii* Taki and Habe*
14. *Bankia philippinensis* Bartsch	*Bankia tenuis* Sivickis
15. *Bankia johnsoni* Bartsch	*Bankia osumiensis* Mawatari and Kitamura*
16. *Bankia campanellata* Moll and Roch	
17. *Bankia fimbriatula* Moll and Roch	

Table 2 continued.

18. *Teredothyra smithi* (Bartsch)	*Kuphus kiiensis* Taki and Habe *Kuphus smithi* (Bartsch) *Teredo radclifei* Bartsch
19. *Teredothyra matocotana* (Bartsch)	*Kuphus matocotana* (Bartsch)
20. *Kuphus polythalamia* (Linnaeus)	*Dicyathifer polythalamia* (Linnaeus)
21. *Nototeredo edax* (Hedley)	*Psiloteredo pentagonalis* Taki and Habe* *Psiloteredo hydei* Sivickis *Psiloteredo kirai* Taki and Habe *Psiloteredo yakushimae* Habe* *Psiloteredo septa* Mawatari and Kitamura*
22. *Uperotus clavus* (Gmelin)	*Glumebra shionomisakiensis* Taki*
23. *Teredora princesae* (Sivickis)	*Teredora aurita* (Hedley)* *Teredora sparcki* (Roch)
24. *Zachsia zenkewitschi* Bulatoff and Rjabtschikoff	
25. *Bactronophorus thoracites* (Gould)	*Bactronophorus philippinensis* (Bartsch)

*: Questionable, further examination is needed.

I-2. Distribution of the Shipworms found in Test Panels submerged in Japanese Waters

I-2-1. Materials and Method

A test panel (Pinus densiflora Sieb. et Zucc., 5 x 2 cm in section and 20 cm in length) with a center hole for rope penetration was used in the present investigation. Three test panels constituted a test string for obtaining the precise information on what species of shipworm existed at 33 test localities in Japan.

The test string was immersed at each test locality, as 3 test panels were between 30 and 100 cm below the surface of the water. Test panels were exposed to shipworm attack for at least a month to 4 months during the period from May, 1974 through October, 1976, and then brought back to the laboratory. After removal of test panels, surface debris and fouling organisms were scraped off prior to taking specimens out of the panels. Specimens were identified under a binocular stereoscopic microscope. Identification was made by Turner's key (Turner, 1971).

I-2-2. Results and Discussion

In the present investigation 9 species of shipworms were found: Teredo navalis Linnaeus, Teredo furcifera von Martens, Lyrodus pedicellatus (Quatrefages), Bankia carinata (Gray), Bankia campanellata Moll and Roch, Bankia johnsoni Bartsch, Bankia bipennata (Turton), Teredora princesae (Sivickis) and Nototeredo edax (Hedley).

Teredo navalis Linnaeus and Lyrodus pedicellatus (Quatrefages) were widely distributed in Japanese waters as species identified are shown in Table 3 with test localities.

Table 3. Shipworms found along the coasts of Japan.

(O: species found, -: not found)

Locality \ Species [a)]	1	2	3	4	5	6	7	8	9
1. Muroran, Hokkaido	-	-	-	-	-	-	-	-	-
2. Hakodate, Hokkaido	-	-	-	-	-	-	-	-	-
3. Onagawa, Miyagi	O	-	-	-	-	-	-	-	-
4. Sado, Niigata	O	-	-	O	-	-	-	-	-
5. Noto, Ishikawa	O	O	O	-	-	-	-	-	-
6. Kawasaki, Kanagawa	-	-	-	-	-	-	-	-	-
7. Oppama, Kanagawa	O	-	-	-	-	-	-	-	-
8. Aburatsubo, Kanagawa	O	-	-	-	O	-	-	-	-
9. Shimizu, Shizuoka	-	-	-	-	-	-	-	-	-
10. Nagoya, Aichi	-	-	-	-	-	-	-	-	-
11. Yokkaichi, Mie	O	-	-	-	-	-	-	-	-
12. Toba, Mie	O	-	O	-	-	-	-	-	-
13. Tatoku Island, Mie	O	-	O	O	-	-	-	-	-
14. Takahama, Fukui	O	-	O	O	-	-	-	-	O
15. Maizuru, Kyoto	O	-	O	-	-	-	-	-	-
16. Sakai, Osaka	-	-	-	-	-	-	-	-	-
17. Wakayama, Wakayama	O	-	-	-	-	-	-	-	-
18. Kainan, Wakayama	-	-	-	-	-	-	-	-	-
19. Arita, Wakayama	O	-	O	O	-	-	-	O	-
20. Yura, Hyogo	O	-	-	O	-	-	-	-	-
21. Aioi, Hyogo	O	-	-	-	-	-	-	-	-
22. Naruto, Tokushima	O	O	O	-	O	-	-	-	-
23. Sakaide, Kagawa	O	-	O	-	-	-	-	-	-
24. Uno, Okayama	O	-	O	-	-	-	-	-	-
25. Mizushima, Okayama	O	-	O	-	-	-	-	-	-
26. Kure, Hiroshima	O	-	-	-	-	-	-	-	-
27. Miyajima, Hiroshima	O	-	O	-	-	-	-	-	-
28. Shimonoseki, Yamaguchi	O	-	O	-	-	-	-	-	-
29. Kokura, Fukuoka	O	-	-	-	-	-	-	-	-
30. Tobata, Fukuoka	-	-	-	-	-	-	-	-	-
31. Nagasaki, Nagasaki	O	-	O	-	-	-	-	-	-
32. Koniya, Kagoshima	-	-	O	O	-	O	O	-	-
33. Naha, Okinawa	-	O	O	-	-	-	O	-	-

a) 1: Teredo navalis Linnaeus, 2: Teredo furcifera von Martens, 3: Lyrodus pedicellatus (Quatrefages), 4: Bankia carinata (Gray), 5: Bankia campanellata Moll and Roch, 6: Bankia johnsoni Bartsch, 7: Bankia bipennata (Turton), 8: Teredora princesae (Sivickis), 9: Nototeredo edax (Hedley).

Nototeredo edax (Hedley) was found in a sunken log which had been previously imported from the west coast of U.S.A. into Takahama, Fukui Pref. This species, which is not distributed along the west coast of U.S.A., obviously exists at Takahama.

Teredo navalis Linnaeus is widely distributed in Japanese waters, and found at 23 localities this time as shown in Fig. 1 (see also Table 3) with early locality records in the literature. This species is always found dominantly at a locality where shipworms actively work with exceptions at Naha and Koniya, though generally plural species of shipworms are present there. Teredo navalis Linnaeus appeared as a single species at 7 localities (i. e. Onagawa, Yokkaichi, Wakayama, Oppama, Aioi, Kure, and Kokura), and the number of animals obtained from test panels was quite few without any exception. In addition, the body lengths of the animals did not exceed 20 mm even in the case of 2 month submergence in the summer season. This species is short-term larviparous: larvae are released from the adults into the water as straight-hinge veligers, and they spend a relatively long free-swimming period before settling on the surface of wood. That is, the animals are one of so-called " ocean travellers " (Edmondson,

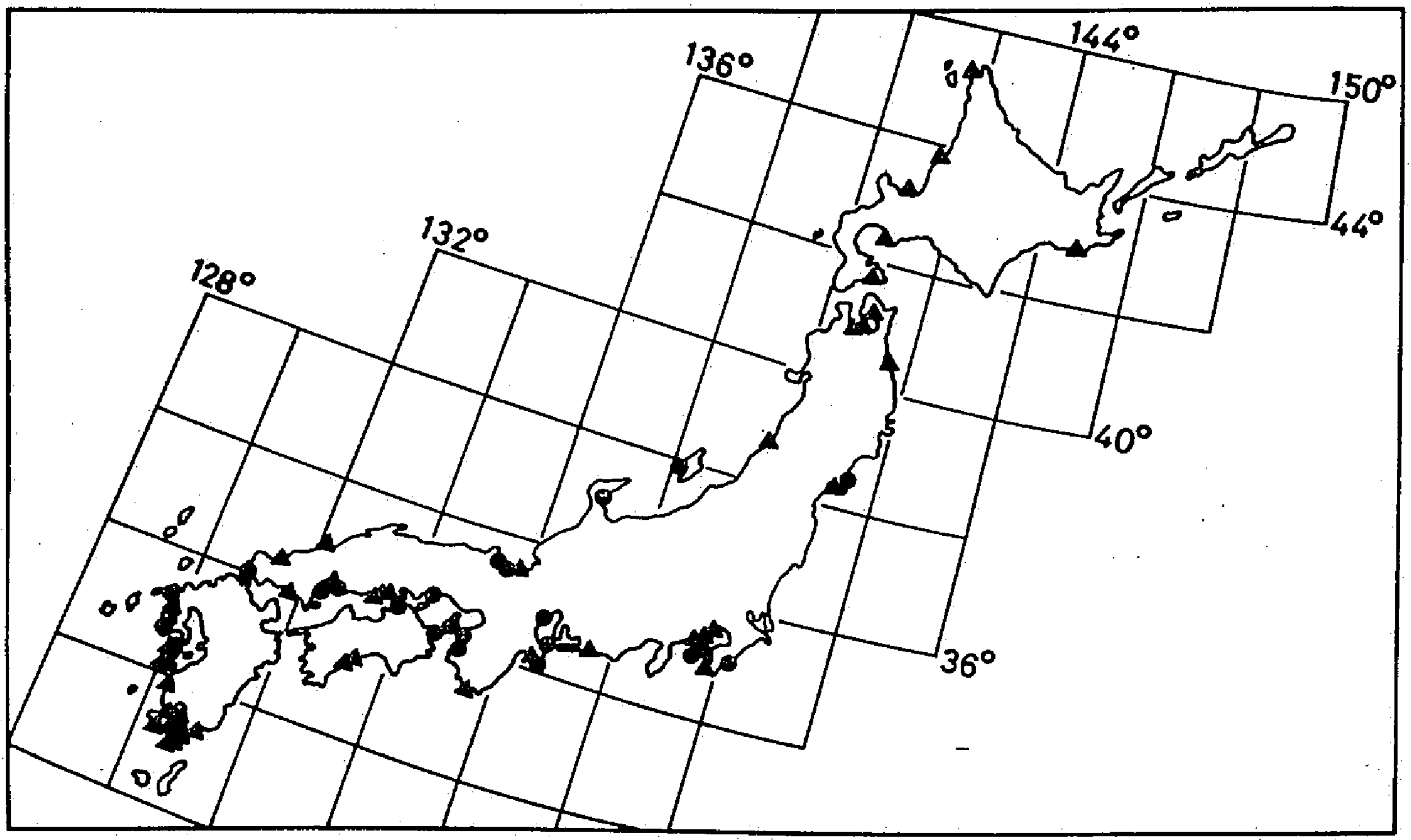

Fig. 1. Distribution of Teredo navalis Linnaeus along the coasts of Japan (●: Specimens seen, ▲: Literature).

1962) moving horizontally and vertically over a wide range. Therefore, it is possible that the larvae disperse for a long distance with a tidal current and succeed in penetrating into wood at a locality where the species is not indigenous. Even if not indigenous or if the species should be indigenous with a scant occurrence at a given locality, the animal can settle down there when wood is incessantly supplied as food, such as the case in sea water log storage areas. Consequently, repetitious investigations may possibly be able to reveal the occurrence of Teredo navalis Linnaeus even at localities with no shipworm present, because the species, in many cases, exists in the adjacent waters.

Distribution of the second commonest Lyrodus pedicellatus (Quatrefages) almost overlaps that of the above species, but locality records are a little scantier as seen in Fig. 2. This species, a long-term larviparous, retains larvae until the pediveliger stage, and the larvae have a short free-swimming period. It therefore appears that the larvae of Lyrodus pedicellatus (Quatrefages) can not travel over a long distance in their larval life but settle on new wood in the vicinity of attacked wood of a specified locality indigenously.

Of other species present, Bankia carinata (Gray) is relatively common along the coasts of Japan, provided that the distribution is restricted to the west of Tokyo and to the south of Sado (see Fig. 3).

On the basis of the early locality records, Teredo furcifera von Martens is found only in Shikoku and Kyushu, but

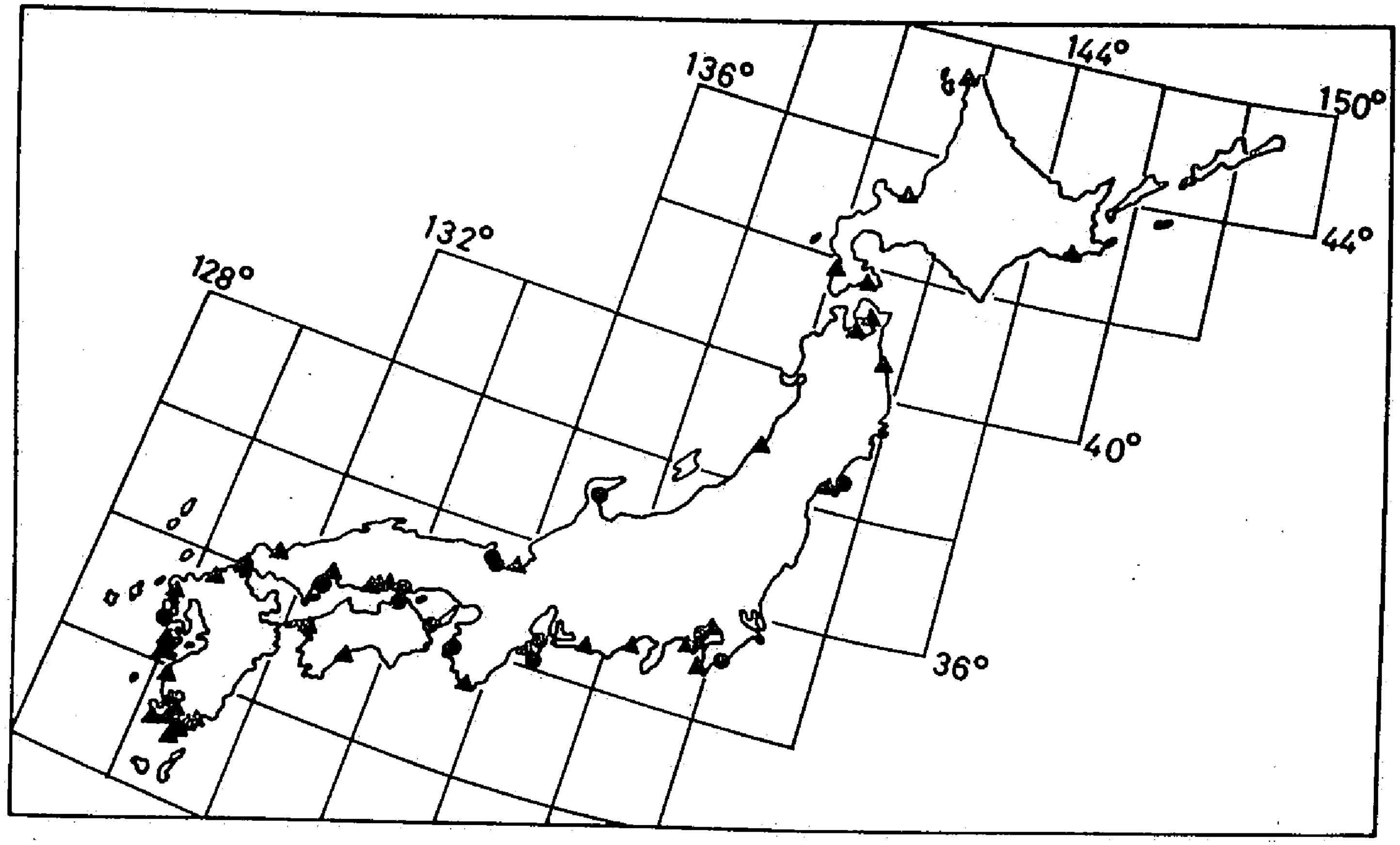

Fig. 2. Distribution of Lyrodus pedicellatus (Quatrefages) along the coasts of Japan (●: Specimens seen, ▲: Literature).

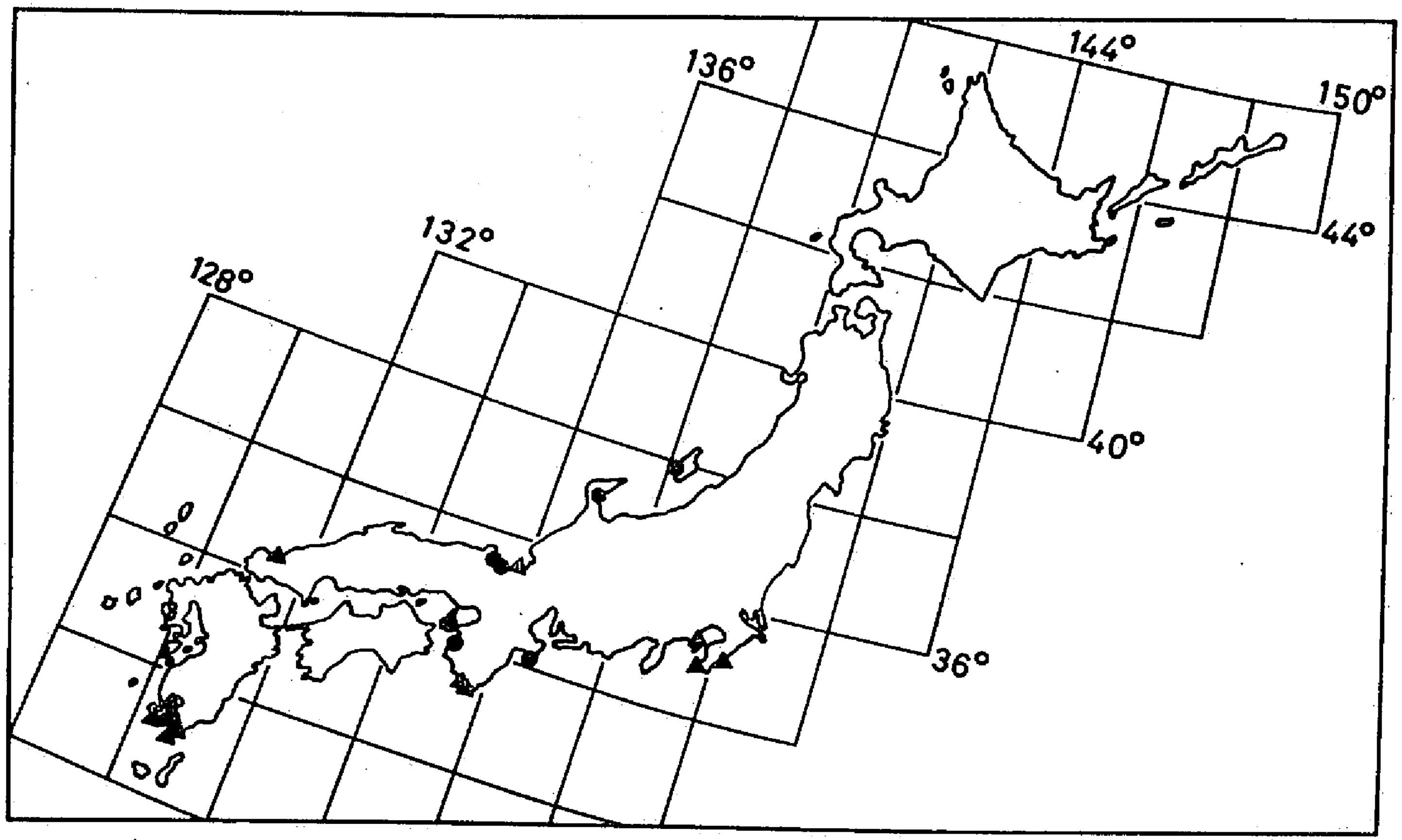

Fig. 3. Distribution of Bankia carinata (Gray) along the coasts of Japan (●: Specimens seen, ▲: Literature).

the present results show that this species is found even at Noto. It is very likely that larvae which had been discharged from the adults in wooden hull or drift timber succeeded in boring into test panels in the summer when water temperature was over 25°C (Tsunoda and Nishimoto, 1976) since the adults of the species, known as a tropical to subtropical species originally, can survive even in freezing water and prolong the brooding of the young until the favorable conditions for spawning larvae are recovered (Turner, 1966). Otherwise, this species is indigenous there, though an addtional work is needed on this point.

Bankia campanellata Moll and Roch, which may possibly be confused with *Bankia carinata* (Gray), was newly recorded at Aburatsubo and Naruto, and the species was not abundant in number.

Bankia johnsoni Bartsch, *Bankia bipennata* (Turton), *Teredora princesae* (Sivickis) and *Nototeredo edax* (Hedley) were occasionally found among the predominant species such as *Teredo navalis* Linnaeus and *Lyrodus pedicellatus* (Quatrefages). The tendency of distribution of these minor species, together with the early records, is summarized as follows: *Bankia johnsoni* Bartsch is limitted only in Kagoshima Pref.; *Bankia bipennata* (Turton) in Chiba Pref, Kagoshima Pref. and Okinawa Pref.; *Teredora princesae* (Sivickis) in Wakayama Pref. and Kagoshima Pref.; *Nototeredo edax* (Hedley) in Wakayama Pref., Fukui Pref., Nagasaki Pref. and Kagoshima Pref. These are all tropical species as demonstrated by the locality records in the world (Turner, 1966;

Nair and Sarawathy, 1971) and MCZ[1] collection of specimens. The possibility of finding these animals in test panels consequently is quite rare in northern waters, though the shipworms can be found in a drift timber even in cold waters as mentioned before.

For the species not found this time but collected before (see Tables 2 and 3), early locality records and MCZ collection indicate that Lyrodus takanoshimensis (Roch) and Bankia bipalmulata (Lamarck) are found along the southern Pacific coasts of Honshu and Kyushu, Uperotus clavus (Gmelin) and Teredothyra smithi (Bartsch) in Wakayama Pref., Lyrodus affinis (Deshayes), Bankia philippinensis Bartsch and Lyrodus massa (Lamy) in Kyushu, Teredo mindanensis Bartsch and Bankia rochi (Moll) in Shikoku, Teredo triangularis Edmondson in Shikoku and Kyushu, Teredothyra matocotana (Bartsch) in Shikoku and Wakayama Pref., Bankia setacea (Tryon) in Hokkaido, Kuphus polythalamia (Linnaeus) and Bactronophorus thoracites (Gould) in Taiwan[2], and Bankia fimbriatula Moll and Roch in Sagami Bay. Unfortunately, the scant locality records of the above 15 species, in addition to the absence of them in the present investigation, make it impossible to discuss their patterns of distribution at present.
However, Kuphus polythalamia (Linnaeus) and Bactronophorus thoracites (Gould) must be removed from the Japanese ship-

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1) Museum of Comparative Zoology at Harvard University, Cambridge, Massachusetts, U.S.A.

2) Taiwan was a part of Japan when study was made (Taki and Habe, 1945).

worms (see footnote on page 25). Judging from the locality records in a world-wide basis, the incidence of 5 species, i. e. *Uperotus clavus* (Gmelin), *Lyrodus affinis* (Deshayes), *Bankia philippinensis* Bartsch, *Bankia rochi* (Moll) and *Teredo mindanensis* Bartsch is fairly doubtful in Japanese waters (Turner, 1966 and 1971; Nair and Sarawathy, 1971). *Zachsia zenkewitschi* Bulatoff and Rjabtschikoff will also be excluded until the type specimen is examined. Accordingly, the species which are probably found in Japanese waters other than 9 species confirmed in the present investigation are *Teredo triangularis* Edmondson, *Lyrodus takanoshimensis* (Roch), *Lyrodus massa* (Lamy), *Bankia setacea* (Tryon), *Bankia bipalmulata* (Lamarck), *Bankia fimbriatula* Moll and Roch, *Teredothyra smithi* (Bartsch) and *Teredothyra matocotama* (Bartsch).

As discussed above, the distribution of each species of the shipworms along the coasts of Japan requires further work, but it can be summarized anyhow as shown in Table 4.

Table 4. Geographic distribution of the shipworms in Japan.

Shipworm species	Hokkaido	Honshu[a)] South	Honshu[a)] North	Shikoku	Kyushu
1. Teredo navalis	L	P	P	P	P
2. Teredo triangularis	-	-	-	L	P
3. Teredo mindanensis*	-	-	-	L	-
4. Teredo furcifera	-	L	P	P	P
5. Lyrodus pedicellatus	L	P	P	P	P
6. Lyrodus takanoshimensis	-	P**	L**	-	P
7. Lyrodus affinis*	-	-	-	-	L
8. Lyrodus massa	-	-	-	-	P
9. Bankia carinata	-	P	P	-	P
10. Bankia bipalmulata	-	L**	-	-	P
11. Bankia setacea	L	-	-	-	-
12. Bankia rochi*	-	-	-	L	-
13. Bankia johnsoni	-	-	-	-	P
14. Bankia campanellata	-	P**	-	P	-
15. Bankia philippinensis*	-	-	-	-	L
16. Bankia bipennata	-	L**	-	-	P
17. Bankia fimbriatula	-	L**	-	-	-
18. Teredothyra smithi	-	L**	-	-	P
19. Teredothyra matocotana	-	L**	-	L	-
20. Teredora princesae	-	P**	-	-	-
21. Uperotus clavus*	-	-	-	L	-
22. Nototeredo edax	-	P**	-	L	L

a) Boundary between South and North is 36°N.

*: Occurrence is questionable in Japanese waters.

**: Locality records are restricted in the Pacific coast.

P: Specimens seen or finding the species in test panels is specified in the literature.

L: Literature; no specification is given if the species is found in test panels or drift timber or attacked wooden hull. -: Not found.

I-3. Summary

The classification of the Japanese shipworms is fairly confused, and the geographic distribution of the species is not confirmed so far. Therefore, specimens of the shipworms were collected by test panel method at 33 localities along the coasts of Japan. The specimens collected were identified according to the new Turner's systematics to discuss the pattern of distribution of the shipworms in Japanese waters together with the results of the early works reviewed.

Of 25 species which appeared in the literature (Table 2), 7 species are questionable of the occurrence in Japanese waters: *Bactronophorus thoracites* (Gould), *Kuphus polythalamia* (Linnaeus), *Teredo mindanensis* Bartsch, *Lyrodus affinis* (Deshayes), *Bankia rochi* (Moll), *Bankia philippinensis* Bartsch, and *Uperotus clavus* (Gmelin). And another questionable species is *Zachsia zenkewitschi* Bulatoff and Rjabtschikoff because of the lack of sufficient description and illustration of Japanese materials.

In the present investigation, 9 species were found (Table 3): *Teredo navalis* Linnaeus at Onagawa, Sado, Noto, Oppama, Aburatsubo, Yokkaichi, Toba, Tatoku Is., Takahama, Maizuru, Wakayama, Arita, Yura, Aioi, Naruto, Sakaide, Uno, Mizushima, Kure, Miyajima, Shimonoseki, Kokura, and Nagasaki; *Teredo furcifera* von Martens at Noto, Naruto, and Naha; *Lyrodus pedicellatus* (Quatrefages) at Noto, Toba, Tatoku Is., Takahama, Maizuru, Arita, Naruto, Sakaide, Uno, Mizushima, Miyajima, Shimonoseki, Nagasaki, Koniya, and Naha; *Bankia carinata* (Gray) at Sado, Tatoku Is., Takahama, Arita, Yura, and Koniya; Bankia campanellata Moll and Roch at Aburatsubo and Naruto; Bankia johnsoni Bartsch at Koniya; Bankia bipennata (Turton) at Koniya and Naha; Teredora princesae (Sivickis) at Arita; Nototeredo edax (Hedley) at Takahama.

Teredo navalis Linnaeus and Lyrodus pedicellatus (Quatrefages) are widely distributed in Japanese waters (Figs. 1 and 2). Bankia carinata (Gray) is relatively common, but the distribution is restricted only in southern parts (Fig. 3). Bankia johnsoni Bartsch, Bankia bipennata (Turton) and Teredora princesae (Sivickis) are found also only in southern parts.

For Teredo furcifera von Martens, Bankia campanellata Moll and Roch and Nototeredo edax (Hedley), the patterns of distribution are not evident because of insufficient locality records. The species which are absent in the present investigation but recorded before are generally distributed in southern areas with an exception of Bankia setacea (Tryon) in Hokkaido.

Further investigation will be able to demonstrate the incidence of the following species along the coasts of Japan: Teredo triangularis Edmondson, Lyrodus takanoshimensis (Roch), Lyrodus massa (Lamy), Bankia fimbriatula (Bartsch), Bankia bipalmulata (Lamarck), Bankia setacea (Tryon), Teredothyra smithi (Bartsch), and Teredothyra matocotana (Bartsch).

II. Season of Settlement

Many papers have been concerned with the season of shipworm settlement in the world because the appropriate comprehension of the subject is a significant step to understand the shipworm problem at given localities.

As mentioned before, marine borer problem in the present-day Japan is centered on the shipworm attack on the imported logs stored in the sea. The import of logs into Japan has remarkably increased in recent years, and this trend will continue for some time. The amount of imported logs occupies more than 60 % of Japan's total wood supply. The imported logs are transported by ships into over 100 international trading ports along the coasts of Japan.

The logs are generally stored in sea water for classification, inspection and plant quarantine, and at least 10 to 20 days are needed for these operations. Some logs are occasionally stored in the sea for a month to 6 months at the longest. During the period of storing logs in sea water, the logs are inevitably exposed to the marine borers.

Marine borers, including genus Teredo, Limnoria and Martesia, are well known pests to untreated wooden structures, wooden ships and logs. The most hazardous marine pests to the logs stored in the sea are the marine wood-boring molluscs belonging to family Teredinidae, as they degrade logs even during short-term storage.

In 1969, a great economic loss was caused by shipworms in the sea water log storage area at Uchiura Port, Takahama, Fukui Pref. As the occurrence and settling season of shipworms at the port were unkown, no counterplan was considered against the tremendous destructive power of the animals.

At present, it is therefore emphasized that the reasonable use of storing areas, harbor hygiene, and protection methods are needed for preventing shipworm attack. Consequently, it is firstly desirable to investigate the season of settlement of shipworm larvae in relation to the species of shipworms present at specified localities because only the reliable way to reduce and/or to prevent the economic loss caused by shipworm attack is taking ashore as early as possible.

In this part, monthly settlement of shipworms is determined by test panel method in consideration of water temperature and salinity at 14 localities along the coasts of Japan: Onagawa, Sado, Oppama, Aburatsubo, Noto, Tatoku Is., Aioi, Uno, Miyajima, Shimonoseki, Nagasaki, Naha, Naruto and Takahama.

II-1. Investigations during the Period from May, 1974 to April, 1975

II-1-1. Materials and Method

At 12 test localities, monthly settlement of shipworms was determined by test panel method. Test localities are shown in Fig. 4: 1) Onagawa, 2) Sado, 3) Oppama, 4) Aburatsubo, 5) Noto, 6) Tatoku Is., 7) Aioi, 8) Uno, 9) Miyajima, 10) Shimonoseki, 11) Nagasaki, and 12) Naha.

A test panel (sapwood of *Pinus densiflora* Sieb. et Zucc., 5 x 2 cm in section and 20 cm in length) with a hole at the center for rope penetration was employed. Three test panels constituted a test string for obtaining the precise information on the monthly settlement. The test string was submerged vertically in the sea from an experimental raft or some other floating structures, as 3 panels were between 30 and 100 cm below the surface of the water. The test string was renewed every month to examine the monthly settlement of shipworms for a year from May, 1974 to April, 1975.

After removal of the test panels, surface debris and fouling organisms were scraped off for counting the number of shipworm apertures on both upper and lower surfaces per 100 cm^2 under a binocular stereoscopic microscope at low magnification. And the results are shown as the average number of borer punctures on the surfaces of 3 test panels removed at the same time. In addition, water temperature and salinity were measured for discussion.

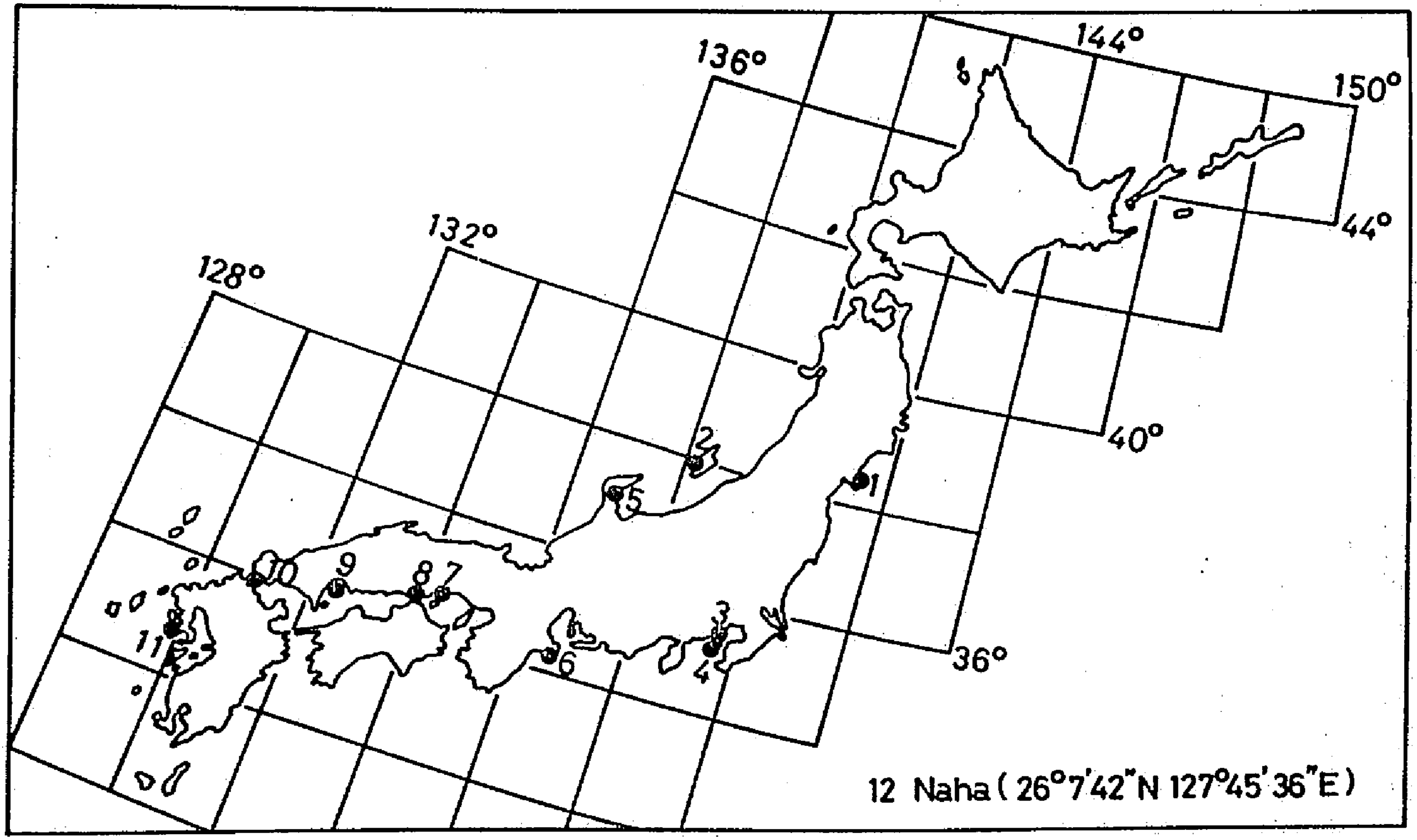

Fig. 4. Test localities at which monthly settlement of shipworms was determined during the period from May, 1974 to April, 1975.

II-1-2. Results and Discussion

II-1-2-1. Monthly Settlement at Onagawa

Only a few specimens of Teredo navalis Linnaeus were found in September and October, 1974, though Imai et al. (1944, 1950) reported the severe attack by Teredo navalis Linnaeus and Teredo yatsui Moll (= a synonym of Lyrodus pedicellatus (Quatrefages) after Turner, 1966). The results are shown in Table 5 with a monthly mean water temperature at the surface level.

Table 5. Monthly settlement of shipworms at Onagawa (number of borer apertures per 100 cm^2).

Month	Wood surface Upper	Lower	Water temperature (°C)
May, 1974	0	0	11.0
June	0	0	15.5
July	0	0	18.4
Aug.	0	0	21.5
Sep.	6	2	21.2
Oct.	1	1	18.7
Nov.	0	0	14.5
Dec.	0	0	10.1
Jan., 1975	0	0	7.1
Feb.	0	0	6.4
Mar.	0	0	5.8
Apr.	0	0	6.6

The decrease of wooden ships and structures, which used to give good habitats to the shipworms, has apparently resulted in the decline of shipworms' activity at Onagawa (Tsunoda and Nishimoto, 1976).

II-1-2-2. Monthly Settlement at Sado

The test string was renewed on the 25th every month. As shown in Table 6, settlement of Teredo navalis Linnaeus and Bankia carinata (Gray) was observed in the period from June to January. Bankia carinata (Gray) was found in August, September and November, and was the dominant species during the peak of settlement. Unfortunately, no measurement of water temperature and salinity was made. Although shipworms succeeded in settling on wood for 8 months, they showed the conspicuous pattern of settling season: settlement was concentrated in August and September as shown in Table 6. In addition, particular mention must be made of the occurrence of trace settlement in January, since the settlement is scarcely observed in January in Japanese waters because of low water temperature in winter season.

Table 6. Monthly settlement of shipworms at Sado (number of borer apertures per 100 cm²).

Wood surface	Month M 1974	J	J	A	S	O	N	D	J 1975	F	M	A
Upper	0	1	2	40	31	1	1	1	1	0	0	0
Lower	0	1	1	32	17	1	2	2	0	0	0	0

II-1-2-3. Monthly Settlement at Oppama

Settlement at Oppama was recorded for 6 months from June through November as shown in Table 7 with water temperatures and salinities measured at the removal of test panels.

Teredo navalis Linnaeus was found as a single species at the test site, and only a few individuals succeeded in settling on wood. The first settlement began in June when water temperatures were over 20° C. No shipworm settled at temperatures below 17° C. *Teredo navalis* Linnaeus at Oppama seems to be adapted for a small range of water temperatures in comparison with the same species at the other test localities. It is, however, possible that no settlement in December is simply reflected by the scanty occurrence of shipworms at Oppama (see also the results at Aburatsubo mentioned below).

Table 7. Monthly settlement of shipworms at Oppama (number of borer apertures per 100 cm^2).

Month	Wood surface Upper	Lower	Water temperature (°C)	Salinity (‰)
May, 1974	0	0	22.0	30.72
June	1	0	22.0	30.72
July	3	1	24.0	32.80
Aug.	13	1	26.0	32.88
Sep.	1	1	22.0	35.35
Oct.	1	0	18.5	29.54
Nov.	1	1	17.0	31.70
Dec.	0	0	11.0	32.08
Jan., 1975	0	0	10.0	33.17
Feb.	0	0	9.0	31.12
Mar.	0	0	13.0	32.53
Apr.	0	0	18.5	30.86

II-1-2-4. Monthly Settlement at Aburatsubo

Though water temperatures and salinities were not measured, they probably do not differ much from those at Oppama because the test locality is situated near Oppama (see Fig. 4). *Teredo navalis* Linnaeus and *Bankia campanellata* Moll and Roch occurred from June to December. But no attack was found in August (see Table 8). *Teredo navalis* Linnaeus was dominantly found at the test site. The extent of shipworm attack was generally very slight.

Table 8. Monthly settlement of shipworms at Aburatsubo (number of borer apertures per 100 cm^2).

Wood surface	M 1974	J	J	A	S	O	N	D	J 1975	F	M	A
Upper	0	5	1	0	3	1	0	1	0	0	0	0
Lower	0	1	3	0	18	6	1	0	0	0	0	0

II-1-2-5. Monthly Settlement at Noto

Borer apertures on the wood surfaces were observed for 9 months from June to February with a remarkable peak in September as shown in Fig. 5 and Table 9. The peak of settlement did not agree with the period with the highest water temperatures, but it preferably appeared in a transition stage when water temperature began to fall (Table 9). The similar tendency was obtained at Takahama, Fukui Pref. when examining test blocks submerged under floating condition (Tsunoda and Nishimoto, 1972).

The first settlement started in June when water temperatures were over 20° C, whereas the larvae of shipworms penetrated into wood even at low water temperature below 15° C in December, January and February. A rise of water temperature in spring must have obviously stimulated the reproductive activity of the adult shipworms. The results obtained here also evidenced that the animals could breed posterity at around 10° C. (Grave, 1928).

The number of shipworms found in test panels submerged in January and February was few, and it was impossible to identify species which bored into wood. The more settlement of shipworms is generally observed on the upper surfaces of test blocks (Walden et al., 1967). On the contrary, the lower surfaces were infested with shipworms more severely than the upper ones at Noto (Tsunoda and Nishimoto, 1976).

Table 9. Monthly settlement of shipworms at Noto (number of borer apertures per 100 cm^2).

Month	Wood surface Upper	Wood surface Lower	Water temperature (°C)*	Salinity* (‰)
May, 1974	0	0	17.4	35
June	4	5	21.8	37
July	6	9	24.4	36
Aug.	59	372	26.0	36
Sep.	223	1097	23.2	35
Oct.	31	232	21.3	36
Nov.	18	189	15.6	34
Dec.	3	25	11.8	33
Jan., 1975	1	7	10.7	33
Feb.	0	1	10.5	34
Mar.	0	0	10.6	34
Apr.	0	0	14.6	33

*: Water temperature and salinity were measured at the surface level once a month at replacing a test string.

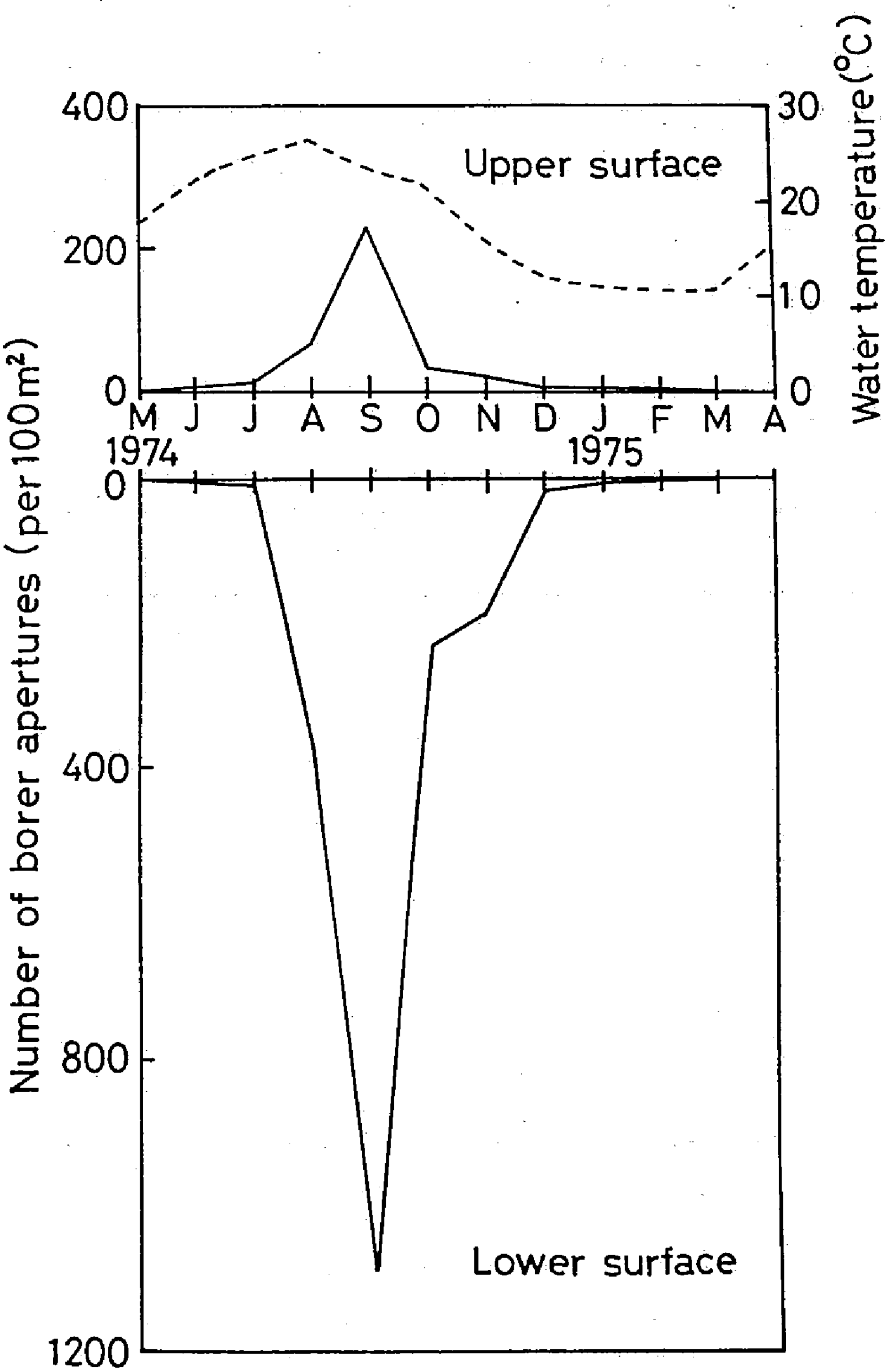

Fig. 5. Monthly settlement of shipworms at Noto for the period from May, 1974 to April, 1975.

——: Number of borer apertures per 100 cm^2

----: Water temperature at the surface level

II-1-2-6. Monthly Settlement at Tatoku Is.

Water depth at the test site is about 15 m. Three test panels were vertically submerged at 15, 30 and 45 cm respectively below the surface of the water.

Results on the monthly settlement of shipworms at Tatoku Is. are shown in Table 10 together with monthly mean water temperatures.

Table 10. Monthly settlement of shipworms at Tatoku Is. (number of borer apertures per 100 cm^2).

Month	Wood surface Upper	Lower	Water temperature (^{o}C)
May, 1974	0	0	19.5
June	1	0	23.8
July	5	3	26.0
Aug.	5	3	29.1
Sep.	4	0	26.6
Oct.	3	3	22.5
Nov.	0	1	17.9
Dec.	0	0	12.8
Jan., 1975	0	0	12.9*
Feb.	0	0	11.7
Mar.	0	0	10.3
Apr.	0	0	14.6

*: Measurement was made only twice in the period.

Shipworm attack was observed for 6 months from June through November. Number of borer punctures on the wood surfaces was much fewer than that expected from the result of the preliminary investigation in September-November, 1973 (Tsunoda and Nishimoto, 1976). According to the fact that test panels were exposed to shipworm attack for a longer period in the preliminary investigation, test panels were infested with over 200 borers per 100 cm^2 each on both upper and lower surfaces.

Teredo navalis Linnaeus and Lyrodus pedicellatus (Quatrefages) were identified this time, but Bankia carinata (Gray) was relatively abundant in the test panels submerged from September to November, 1973.

II-1-2-7. Monthly Settlement at Aioi

Results on the monthly settlement of shipworms are tabulated in Table 11 with water temperature and salinity at the surface level.

Table 11. Monthly settlement of shipworms at Aioi (number of borer apertures per 100 cm^2).

Month	Wood surface Upper	Wood surface Lower	Water temperature (°C)*	Salinity (‰)*
May, 1974	0	0	19.0	29.7
June	0	0	25.5	28.2
July	54	34	28.0	26.4
Aug.	4	8	29.0	25.7
Sep.	Lost		24.3	28.0
Oct.	12	9	20.8	28.4
Nov.	6	2	12.5	28.4
Dec.	1	0	9.2	28.9
Jan., 1975	0	0	7.0	27.5
Feb.	0	0	7.6	29.0
Mar.	0	0	10.1	30.3
Apr.	0	0	16.2	23.3

*: Measurement was made only once in the period at removing test panels.

Shipworms succeeded in settling on wood for 6 months from June through December. It would appear that the settling period has the pattern with 2 peaks in July and September as found in Naruto (described later), though test panels were unfortunately lost in September. Two-peak type of the season of settlement may possibly be characterized by the sudden decline in August with the highest water temperatures through the year. Only a single shipworm species, Teredo navalis Linnaeus was ascertained at the test site.

II-1-2-8. Monthly Settlement at Uno

Test panels were replaced every 25th of the month, but no measurement of water temperature and salinity was made.

Occurrence of shipworm attack by Teredo navalis Linnaeus and Lyrodus pedicellatus (Quatrefages) was observed for 7 months from June through December. In August, September and October, in which shipworm attack was expected, test panels were unfortunately lost so that settling peak was not determined on the basis of the present results tabulated below (Table 12).

Table 12. Monthly settlement of shipworms at Uno (number of borer apertures per 100 cm^2).

Wood surface	M 1974	J	J	A	S	O	N	D	J 1975	F	M	A
Upper	0	1	208	Lost			31	1	0	0	0	0
Lower	0	2	44				44	0	0	0	0	0

II-1-2-9. Monthly Settlement at Miyajima

Of 2 species of shipworms present (see Table 3 on page 18), Lyrodus pedicellatus (Quatrefages) was dominant at the test locality. Water temperature and salinity were measured once a month at the time of removal of test panels. In July, the occurrence of red tide was observed around the test area. The sudden decrease in salinity caused by much rainfall seemed to eradicate the planktonic lives. And that probably resulted in the fact that shipworm larvae could not penetrate into wood in the period because of the lack of oxygen. Results on the monthly settlement of shipworms are shown in Table 13 together with water temperature and salinity at the surface level. Those revealed that settlement occurred for just 5 months from June through October with a marked peak in September (Fig. 6). Water temperatures in November were high enough for the animals to bore into wood substrate, but no attack was definitely demonstrated in the month.

Table 13. Monthly settlement of shipworms at Miyajima (number of borer apertures per 100 cm^2).

Month	Wood surface Upper	Wood surface Lower	Water temperature (°C)	Salinity (‰)
May, 1974	0	0	19.0	31.8
June	5	5	21.0	30.4
July	0	0	23.0	23.1
Aug.	36	46	26.0	29.1
Sep.	163	70	24.0	34.3
Oct.	11	6	20.0	34.3
Nov.	0	0	21.0	37.2
Dec.	0	0	11.0	31.6
Jan., 1975	0	0	7.8	30.9
Feb.	0	0	7.6	31.8
Mar.	0	0	12.0	31.8
Apr.	0	0	9.5	35.9

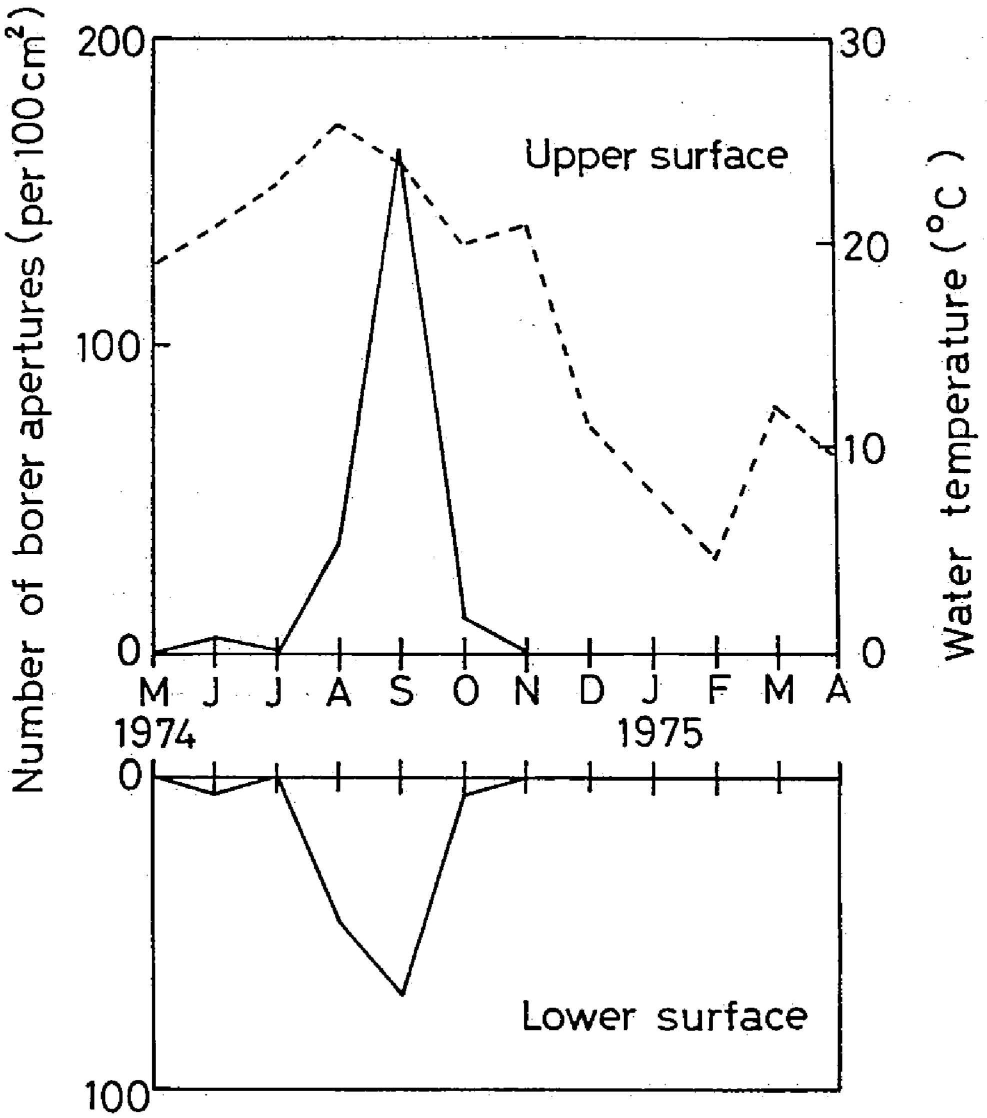

Fig. 6. Monthly settlement of shipworms at Miyajima for the period from May, 1974 to April, 1975.

——: Number of borer apertures per 100 cm^2

----: Water temperature

II-1-2-10. Monthly Settlement at Shimonoseki

Of 2 species of shipworms present (see Table 3 on page 18), <u>Teredo</u> <u>navalis</u> Linnaeus was the commoner. Shipworm attack was observed for 5 months from July through November. Borer punctures found on the surfaces were not abundant in number as shown in Table 14. Data on water temperatures and salinities were obtained at the replacement of a test string.

Table 14. Monthly settlement of shipworms at Shimonoseki (number of borer apertures per 100 cm^2).

Month	Wood surface Upper	Lower	Water temperature (°C)	Salinity (‰)
May, 1974	0	0	-*	-*
June	0	0	-	-
July	5	3	-	-
Aug.	12	18	-	-
Sep.	7	16	24.1	32.5
Oct.	0	1	20.0	30.5
Nov.	1	2	15.7	32.1
Dec.	0	0	12.9	33.7
Jan., 1975	0	0	11.8	34.4
Feb.	0	0	10.8	27.9**
Mar.	0	0	13.3	33.6
Apr.	0	0	17.2	32.5

*: No measurement was made.

**: Noctilucae occurred abnormally in the period.

II-1-2-11. Monthly Settlement at Nagasaki

Shipworm attack occurred for 6 months from July through December with the range of water temperatures between 16.0° and 26.0° C. The peak of infestation was not evident, but would appear in October. Of 2 species of shipworms found at the test site (see Table 3 on page 18), Teredo navalis Linnaeus was predominant. The results are given in Table 15 and Fig. 7.

Table 15. Monthly settlement of shipworms at Nagasaki (number of borer apertures per 100 cm^2).

Month	Wood surface Upper	Wood surface Lower	Water temperature (°C)*	Salinity (‰)*
May, 1974	0	0	20.5	31.8
June	0	0	22.0	32.3
July	1	0	24.0	23.1**
Aug.	5	1	26.0	31.8
Sep.	70	9	25.0	39.4
Oct.	55	90	23.0	38.7
Nov.	17	72	21.0	39.4
Dec.	0	1	16.0	41.5
Jan., 1975	0	0	13.0	34.1
Feb.	0	0	10.3	31.1
Mar.	0	0	14.0	36.7
Apr.	0	0	22.5	31.6

*: Measurement was made only once in the period at removing test panels.

**: Low salinity possibly depended on a lot of rainfall.

II-1-2-12. Monthly Settlement at Naha

Three species of shipworms were found in collecting panels submerged from August 23 to October 29, 1974 (see Table 3 on page 18), and Lyrodus pedicellatus (Quatrefages) seemed to be dominant. Shipworm attack was observed for 7 months from June, though test panels were not recovered in May. On the basis of the fact that shipworm attack began in May at Koniya (28°08′21″N, 129°18′58″E) (Tsunoda, 1977),

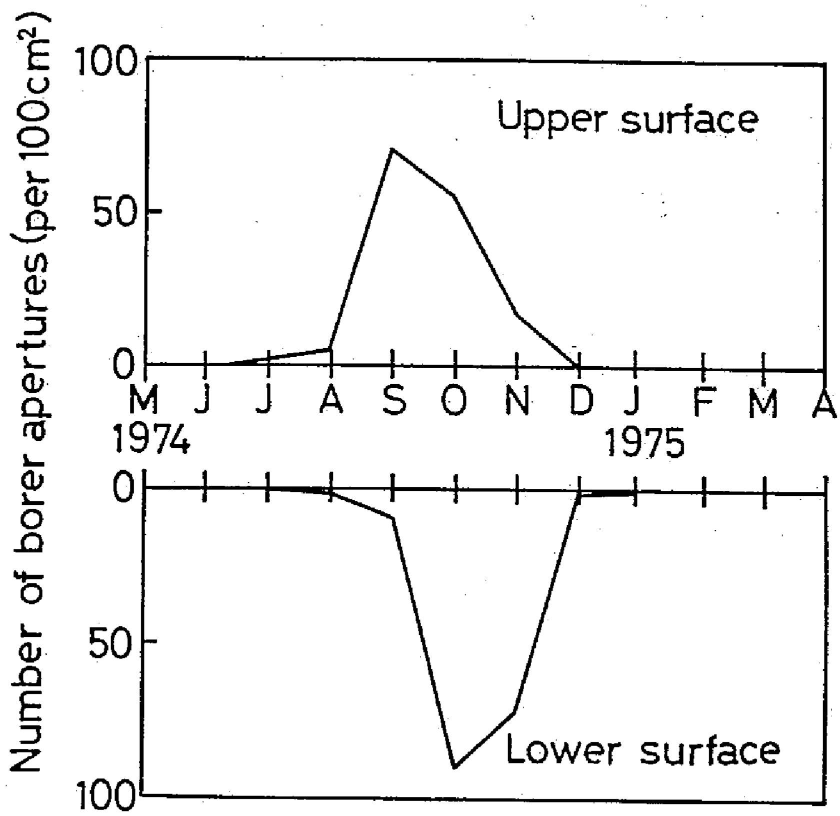

Fig. 7. Monthly settlement of shipworms at Nagasaki for the period from May, 1974 to April, 1975.

it is possible that the shipworms settle on wood surfaces in May at Naha. As the results are tabulated below (Table 16), initial entry holes of the shipworms on the wood surfaces were not abundant. However, the peak of infestation probably appears in October.

Table 16. Monthly settlement of shipworms at Naha (number of borer apertures per 100 cm^2).

Wood surface	Month J 1974	J	A	S	O	N	D	J 1975	F	M	A
Upper	0	0	2	1	14	3	1	Lost	0	-	-
Lower	0	1	7	5	16	7	0		0	-	-

No measurement of water temperature and salinity was made.

II-2. Investigations at Naruto (1973-1976)

II-2-1. Materials and Method

Investigations were carried out at Naruto (34°12'30"N, 134°36'27"E) for the period from June, 1973 through May, 1976.

Western hemlock (*Tsuga heterophylla* Sargent) test block (4 x 4 cm in section and 30 cm in length) with a center hole for rope penetration was employed in the experiment. Two test blocks were suspended vertically from an experimental raft every month, as the blocks were at 30 and 130 cm respectively below the surface of the water. In the first year (1973), an additional test block was submerged at 80 cm every month.

After removal of the test blocks, surface debris and fouling organisms were scraped off so that number of borer punctures on the wood surfaces (upper, lower and side surfaces) could be counted under a binocular stereoscopic microscope. Number of borer apertures was taken as the criterion of monthly settlement of shipworms.

II-2-2. Results and Discussion

II-2-2-1. Existing Species

Two species, *Teredo navalis* Linnaeus and *Bankia campanellata* Moll and Roch were found in monthly submerged test blocks. *Lyrodus pedicellatus* (Quatrefages) was also present in test blocks submerged for a longer period as shown in Table 17. In addtion, *Teredo furcifera* von Martens was firstly collected from a drift timber, and occasionally found later in test blocks in 1975 and 1976. Of 4 species,

Table 17. Species of shipworms at Naruto and their occurrence during the period from June 1, 1973 to January 27, 1974.

A: Borers apertures found but unidentified.

T: Teredo navalis Linnaeus present.

L: Lyrodus pedicellatus (Quatrefages) present.

B: Bankia campanellata Moll and Roch present.

		Removal date							
		July 1	July 31	Aug. 30	Sep. 29	Oct. 29	Nov. 28	Dec. 28	Jan. 27
Immersion date	June 1	A	T	T	T	T			
	July 1		T	T,L	T	T,L			
	July 31			A	T	T,L			
	Aug. 30				T,B	T			
	Sep. 29					T,B			
	Oct. 29						A		
	Nov. 28							A	
	Dec. 28								A

Teredo navalis Linnaeus was the predominant species at the test site.

As seen in Table 17, Teredo navalis Linnaeus was firstly confirmed in July and found through the period of settlement. Lyrodus pedicellatus (Quatrefages) appeared only in warmer season (August and October). In September and October, the settlement of Bankia campanellata Moll and Roch was demonstrated. The submerging length of only a month seemed to be too short to identify the animals found in a test block, though it was possible to do in July, September and October surely because of favorable conditions for the growth of shipworms.

II-2-2-2. Water Temperature and Salinity

Water temperature was measured, not daily but often, at the surface level, and monthly mean value was calculated (Table 18). Salinity was occasionally measured, and ranged from 32 to 34 ‰ through the periods of the invetigations.

II-2-2-3. Monthly Settlement of Shipworms

On June 1, 1973 the first test blocks were submerged at 30, 80 and 130 cm below the surface of the water, and were renewed every month until May, 1974. From June, 1974 to May, 1976 test blocks were removed only from 30 and 130 cm levels.

Number of borer punctures per 100 cm^2 on the wood surfaces is calculated and tabulated below (Table 19). The average value of the 2 vertical surfaces is indicated as " side " in the tabulation. The horizontal surfaces are divided into " upper " and " lower " surfaces. The aver-

Table 18. Monthly mean water temperatures (°C) at the surface level for the period from June, 1973 to May, 1976.

Month	1973	1974	1975	1976
	Year			
Jan.	-	9.0	10.9	9.7
Feb.	-	8.3	8.8	7.7
Mar.	-	9.5	10.3	9.8
Apr.	-	14.8	14.0	13.4
May	-	18.7	17.5	17.7
June	22.9	22.2	21.9	-
July	27.1	25.5	25.4	-
Aug.	28.0	28.4	27.3	-
Sep.	26.7	26.6	27.9	-
Oct.	23.6	24.3	23.9	-
Nov.	19.6	19.2	19.2	-
Dec.	13.9	14.3	15.1	-

age of all the surfaces is also given as " block ". Moreover, the results at testing depths, 30 and 130 cm, are averaged and shown as " average " in Table 19. The results at 80 cm depth obtained from June, 1973 to May, 1974 are shown in Table 20. No conspicuous difference was perceived among depths.

Table 19. Monthly settlement of shipworms at Naruto (number of borer apertures per 100 cm^2)*.

Year	Month	Depth (cm)	Wood surface Upper	Lower	Side	Block	Average
1973	June	30	16	14	13	14	15
		130	25	10	15	16	
	July	30	29	10	27	23	25
		130	37	19	25	27	
	Aug.	30	4	0	1	2	3
		130	3	1	3	3	

Table 19. continued.

1973	Sep.	30	90	11	43	47	71
		130	160	31	92	94	
	Oct.	30	93	140	96	106	154
		130	256	173	187	201	
	Nov.	30	29	37	29	31	30
		130	25	27	29	28	
	Dec.	30	0	4	1	2	2
		130	1	1	1	1	
1974	June	30	21	8	1	8	6
		130	5	3	2	3	
	July	30	42	7	5	15	14
		130	15	12	11	13	
	Aug.	30	11	11	4	8	7
		130	5	6	5	6	
	Sep.	30	336	46	67	129	116
		130	259	72	40	103	
	Oct.	30	265	448	390	374	494
		130	1002	736	358	614	
	Nov.	30	295	75	154	170	161
		130	272	89	122	152	
	Dec.	30	5	33	16	18	18
		130	3	33	16	17	
1975	June	30	70	25	25	37	28
		130	19	26	14	19	
	July	30	52	34	5	24	22
		130	31	26	11	20	
	Aug.	30	47	24	17	27	27
		130	35	24	23	27	
	Sep.	30	318	102	72	141	128
		130	275	97	42	114	
	Oct.	30	354	226	346	318	314
		130	429	252	277	309	
	Nov.	30	97	119	125	117	135
		130	220	168	110	152	
	Dec.	30	4	69	233	135	111
		130	23	137	91	86	

Table 19. continued.

1976	Jan.	30	1	1	3	2	2
		130	1	3	2	2	
	July	30	0	1	0	1	1
		130	0	0	0	0	
	Aug.	30	5	3	0	2	2
		130	2	0	1	1	
	Sep.	30	5	2	0	2	2
		130	0	1	0	1	
	Oct.	30	18	10	9	12	13
		130	28	11	5	13	
	Nov.	30	12	5	34	22	25
		130	16	22	34	27	
	Dec.	30	0	0	0	0	1
		130	0	3	0	1	

*: Months with no settlement of shipworms are omitted.

Table 20. Monthly settlement of shipworms at 80 cm depth for the period from June, 1973 to May, 1974 (number of borer apertures per 100 cm^2)*.

Month	Wood surface Upper	Lower	Side	Block
June	32	6	15	17
July	47	14	19	25
Aug.	2	1	1	1
Sep.	81	28	64	59
Oct.	173	120	131	139
Nov.	36	29	25	29
Dec.	0	1	1	1

*: No settlement occurred from January to May, 1974.

On the basis of the results given in Tables 19 and 20, settlement of shipworms began in June when water temperatures were over 20°C, and ended in December with water temperatures of 14°-15°C. A conspicuous peak was recorded in October. Larval settlement was occasionally observed in January. When water temperatures began to go down after August, the number of borer apertures found on the wood surfaces suddenly increased. The dominant species at the test site, Teredo navalis Linnaeus releases the larvae at straight-hinge stage. The larvae spend 20 to 30 days in free-swimming stage before settling, though the duration of free-swimming stage might be varied with environmental factors such as water temperature and salinity (e.g. Loosanoff and Davis, 1963; Townsley et al., 1966; Turner, 1966). Subsequently, the larvae which succeeded in penetrating into wood in the fall (September, October and November) had been discharged in August, September and October. The peak in October therefore seemed to have resulted from the advent of sexual maturity of shipworms which burrowed into wood in June, July and August.

As shown in the above tables (Tables 19 and 20), more borer apertures were generally found on the horizontal surfaces than on the vertical ones. Of horizontal surfaces, the upper surfaces were liable to be attacked more severely than the lower surfaces. Similarity was obtained by other investigators (e.g. Walden et al., 1967). Blocks immersed for longer periods confirmatively support the tendency. As an example, a test block immersed at 130 cm depth for 2 months (September and October) suffered 304 shipworm apertures per 100 cm^2 on the upper surface, whereas 61 on the lower one and 95 on the side one.

Difference of shipworm attack with water depths was not demonstrated apparently in the present investigation. However, much heavier infestation was sometimes observed at 130 cm level (e.g. October, 1974).

Longer immersion periods are expected to result naturally in the severer attack as a rule, if the attack is simply interpretted on the basis of the number of borer apertures on the wood surfaces, but the adverse phenomenon was exceptionally noticed (Table 21). Comparison of the results with the cumulative data calculated from Table 20 points out that shipworms which settled on the surfaces of wood would not increase in number proportionally with the increase in the period of immersion. That also suggests that fouling organisms and/or debris accumulated on the surfaces play an important role in preventing the shipworms from settling by reducing potential areas for shipworms' settlement (e.g. Tsunoda and Nishimoto, 1972). Nevertheless, the attack by shipworms develops day by day because the animals keep growing just after initial boring into wood. Therefore, the longer immersion periods finally result in the severer damage.

Table 21. Settlement of shipworms on the wood surfaces of test blocks submerged at 80 cm depth for longer periods (number of borer apertures per 100 cm^2).

Period of immersion (month)	Wood surface Upper	Lower	Side	Block	Cumulative data*
2 (June-July, 1973)	62	25	29	36	42 (17)**
3 (June-Aug., 1973)	31	30	26	28	43 (17)
4 (June-Sep., 1973)	81	28	39	47	102 (17)
5 (June-Oct., 1973)	41	37	40	40	241 (17)
6 (June-Nov., 1973)	104	40	31	52	270 (17)

Table 21. continued.

2 (July-Aug., 1973)	37	21	20	25	26 (25)
3 (July-Sep., 1973)	43	24	14	24	85 (25)
4 (July-Oct., 1973)	44	34	27	33	224 (25)
5 (July-Nov., 1973)	51	39	27	36	253 (25)
2 (Aug.-Sep., 1973)	25	7	8	12	60 (1)
3 (Aug.-Oct., 1973)	19	4	9	10	199 (1)
2 (Sep.-Oct., 1973)	197	68	88	110	198 (59)
3 (Sep.-Nov., 1973)	170	47	58	83	227 (59)
2 (Oct.-Nov., 1973)	282	165	137	180	168 (139)
3 (Oct.-Dec., 1973)	55	28	47	44	169 (139)

*: Data were calculated from the test blocks immersed monthly (see Table 20).

**: Number of borer apertures in the first month of immersion-period is shown in the brackets.

II-3. Investigations at Takahama (1975-1977)

II-3-1. Materials and Method

Investigations were carried out in the sea water log storage area at Otomi, Takahama, Fukui Pref. (Fig. 8).

Four test stations shown as A-D in Fig. 8 were established in the area.

Scotch pine (*Pinus sylvestris* Linnaeus) test block (4 x 4 cm in section and 30 cm in length) was employed to examine monthly settlement of shipworms. Three test blocks were vertically submerged in the sea at 30, 80 and 130 cm, respectively below the surface of the water. The test blocks were replaced every month, and were served to count the borer punctures on the wood surfaces under a binocular stereoscopic microscope at low magnification. Number of borer apertures was taken as the index of the settlement of shipworms.

II-3-2. Results and Discussion

II-3-2-1. Existing Species

On the basis of the examination of test blocks, 3 species of shipworms were identified: Teredo navalis Linnaeus, Lyrodus pedicellatus (Quatrefages) and Bankia carinata (Gray). Nototeredo edax (Hedley) was additionally found in a sinker of western red cedar (Thuja plicata D.Don) which had been previously imported from the Pacific coast of U.S.A. (see page 19). Of 4 species present at the test site, Teredo navalis Linnaeus was by far the commonest. When the damage was discovered in 1975 and 1976, the population density of the species seemed to become relatively higher than usual. Therefore, short-term larviparous species such as Teredo navalis Linnaeus, or oviparous species could explosively disperse their posterity and gametes into the surrounding water.

II-3-2-2. Water Temperature and Salinity

Water temperatures were measured daily at the surface level and monthly mean water temperatures during the period from April, 1975 to March, 1977 are shown in Table 22.

At the test stations A and B, water temperatures were almost the same. And the similarity was also observed at C and D.as shown in Table 22.

Lower temperatures were generally measured near the quay (C and D) in comparison with the records at the test stations A and B. It probably depends on the effect of warm effluent discharged from the new nuclear power station in the vicinity of the test area. Water temperatures seem to have become slightly higher since the power station began to oper-

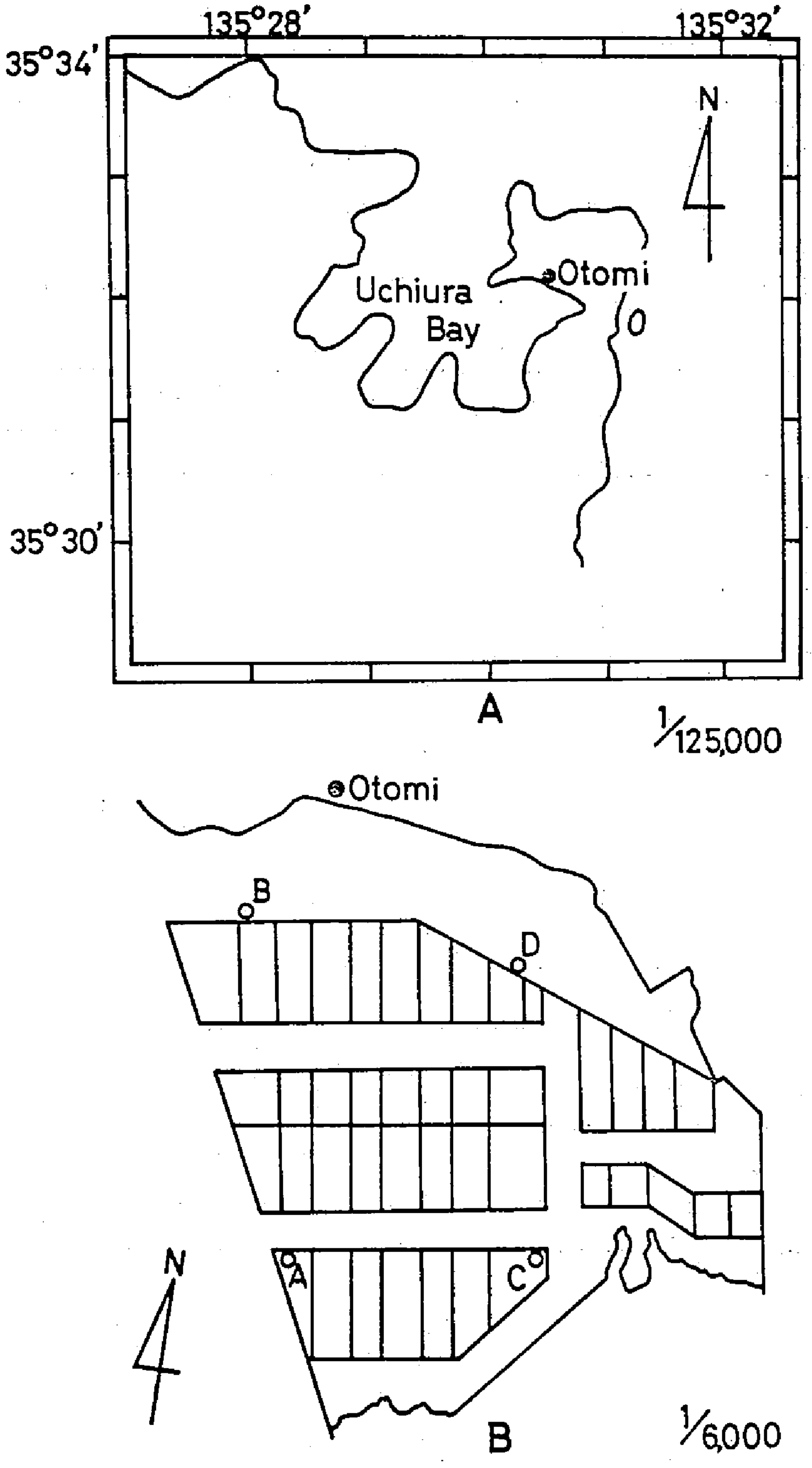

Fig. 8. Test area at Takahama, A: Showing the geographic situation of the sea water log storage area and B: Showing test stations (A-D) in the log storage area.

ate in August, 1974 (Yasuda, 1970; Tsunoda and Nishimoto, 1972).

Measurements on salinity were made sometimes during the course of present investigations. Salinity ranged from 32 to 37 ‰ throughout the course of the investigations.

Table 22. Monthly mean water temperature at the surface level (°C) in Takahama.

Month	Test station A, B	Test station C, D	Month	Test station A, B	Test station C, D
Apr. 1975	14.0	13.9	Apr. 1976	14.4	13.0
May	18.2	18.0	May	17.4	17.3
June	23.5	23.1	June	22.9	22.7
July	27.0	26.9	July	25.6	25.5
Aug.	30.1	29.7	Aug.	28.7	28.7
Sep.	29.0	28.7	Sep.	25.9	25.8
Oct.	25.4	24.9	Oct.	22.3	22.2
Nov.	20.3	20.1	Nov.	19.5	19.5
Dec.	17.1	16.6	Dec.	16.5	16.1
Jan. 1976	13.8	13.2	Jan. 1977	12.2	11.7
Feb.	10.7	10.1	Feb.	8.0	8.0
Mar.	11.1	10.8	Mar.	9.2	9.2

II-3-2-3. Monthly Settlement of Shipworms

In accordance with the same procedures of estimation at Naruto, the results are tabulated below (Table 23). Data in the tabulation are the average of 3 test blocks submerged at 30, 80 and 130 cm depth, respectively.

In the first series from April, 1975 to March, 1976, the larval settlement was observed for 9 months from May, 1975 through January, 1976 with a prominent peak in September. The data in Table 23 assume that after September, when water temperatures fell continuously, the decline of sexual activities agreed with the decrease of larval settlement. There was no settlement in April, 1975, February and March, 1976.

The similar phenomenon was noticed in the second series from April, 1976 to March, 1977, but the settlement began in June and terminated in December.

As shown above, salinity did not seem to be a prevailing hydrographic factor in relation to the settlement of shipworms at the test area, though Nagabhushanam (1962) who investigated the occurrence of shipworms in Visakhapatnam, India testified that the density of settlement was directly related to temperature and salinity. On the other hand, the water temperatures ranged from 8° C in February to 30° C in August with an annual variation of 22° C.

Table 23. Monthly settlement of shipworms at Takahama during the period from April, 1975 to March, 1977 (number of borer apertures per 100 cm^2)*.

Test sta.	Wood surface	May 1975	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan. 1976
A	Upper	1	1	8	39	195	12	8	1	0
	Lower	1	0	1	101	150	11	10	1	0
	Side	1	0	8	59	108	17	4	1	0
	Block	1	1	7	65	140	14	7	1	0
B	Upper	3	0	11	-	116	8	17	4	0
	Lower	1	1	6	-	77	3	24	2	1
	Side	1	0	5	-	79	9	12	2	0
	Block	2	1	7	-	88	7	16	3	1

Table 23. continued.

C	Upper	2	1	6	30	191	4	3	1	0
	Lower	1	10	6	74	259	6	11	1	0
	Side	1	2	7	53	101	5	6	1	0
	Block	2	4	7	53	163	5	7	1	0
D	Upper	1	1	1	31	165	5	7	1	0
	Lower	0	3	8	101	184	9	5	1	0
	Side	0	0	4	44	149	4	8	2	0
	Block	1	1	4	55	162	6	7	2	0

Test sta.	Wood surface	June 1976	July	Aug.	Sep.	Oct.	Nov.	Dec.
A	Upper	2	6	336	13	1	2	1
	Lower	1	9	314	13	4	2	0
	Side	1	8	274	12	2	0	1
	Block	1	8	300	13	2	1	1
B	Upper	0	7	329	7	3	1	0
	Lower	1	12	1452	7	1	1	0
	Side	1	11	600	9	3	1	1
	Block	1	10	745	8	3	1	1
C	Upper	0	11	101	9	5	1	0
	Lower	0	12	240	32	7	3	1
	Side	0	4	112	9	2	1	1
	Block	0	8	141	15	4	2	1
D	Upper	0	4	356	7	2	0	0
	Lower	0	11	326	12	4	2	0
	Side	0	9	213	11	3	1	0
	Block	0	8	277	10	3	1	1

*: Months with no settlement of shipworms are omitted.

: Test blocks lost.

Based on the laboratory test, none of Teredo navalis Linnaeus penetrated into a wood piece at temperatures of either above 26°C or below 14°C (Imai et al., 1950). The present results as shown in Tables 22 and 23, however, indicate that the settlement was observed at temperatures above 26°C in July, August and September, whereas no settlement occurred below 14°C. However, an exception was detected in January, 1976 with monthly mean water temperature of 13.8°C. This suggests that the relative abundance of shipworm settlement is significantly affected by water temperatures, and that the fluctuation of water temperatures throughout the year is rather principal than the mere values of temperatures themselves. The fact that the shipworms began to settle in May, 1975 with monthly mean water temperature of 14.0°C, and in June , 1976 with that of above 22°C well supports the foregoing assumption. It is also of interest to observe that at Kominato, Chiba Pref. (Mawatari, 1950) and Amakusa, Kumamoto Pref. (Murakami, 1958) the shipworms brooded their young forms even in January and February when settlement never occurred at the places. In addition, the temperature impulse stimulates the larval releasing activities of the adults (e.g. Ino, 1958; Culliney et al., 1974). Therefore, the rise of water temperature in May or June, if high enough to release larvae, possibly compels the females which retain larvae to reproduce them without any fertilization in May or June.

Water temperature at the end of settlement was always fairly lower than that at the beginning. And the similar pattern was noted at all test sites. The release of offsprings may possibly require the rise of water temperature to some degree, and that definitely varies with localities because of their own specified change in water temperatures through the year (Imai et al., 1950; Grave, 1928; Nelson, 1928). The larvae once spawned from the parents are able to prolong their planktonic life under unfavorable conditions, and to retard metamorphosing until they find the substrate to settle on. However, the possibility of retardation is naturally restricted. Accordingly, only a few of the larvae discharged in the appropriate time are likely to survive over a relatively long period and to leave finally the trace of attack on the surfaces of wood exceptionally in cold season.

On the results of the season of shipworm settlement at various localities, the efficient factors which affect the shipworm settlement would be deserving of discussion. As described above, shipworms settle on wood for months at various sites along the coasts of Japan. Turbidity and pollution of the waters around test sites definitely affect the activity of shipworms (Nair and Sarawathy, 1971). The effect of them did not seem to abate shipworms' vigor at test localities in the present investigation, though the precise information was not obtained this time.

Environmental factors such as salinity and water temerature, and the amount of wood available for the animals are important agents for the settlement of shipworm larvae.

Salinity requirements are obviously varied with species. *Teredo navalis* Linnaeus, being not only the commonest in Japanese waters but also world-wide in distribution, has a wide range of tolerance to low salinity. *Teredo navalis* Linnaeus reproduced at salinitiy as low as 9 ‰ (Miller, 1926), and 20 out of 30 pediveliger larvae introduced into a container with water of 15 ‰ could bore into wood on the 5th day after introduction (Mawatari, 1950). Imai et al. (1950) demonstrated that the larvae obtained at Onagawa, Miyagi Pref. burrowed successfully at salinities over 14 ‰ in chlorine, and that at 10 ‰ they succeeded in metamorphosing but doubtedly in burrowing. The adult animals distinctly had the wider salinity tolerance, though the extent of tolerance varied with age (Mawatari, 1950). M'Gonigle (1926) who worked in Nova Scotia reported that the boring activity of Teredo navalis Linnaeus was affected at 18 ‰ and was suspended at 10 ‰. Salinity below 6 ‰ was lethal for the adults but they could survive for a month even at 4 ‰ (Blum, 1922).

For Lyrodus pedicellatus (Quatrefages), the second commonest species in Japanese waters, Barrows[1] (1917) pointed out that salinity was important for the distribution of the species in San Francisco Bay and that normal activity was observed at salinity as low as 10 ‰. Imai et al. (1944) showed that the pediveligers of Teredo yatsui Moll (= a synonym of Lyrodus pedicellatus (Quatrefages) after Turner, 1966) were the most vigorous at about 18 ‰ in chlorine, and that they seemingly succeeded in excavating into wood at 15 ‰. Boring activity was questionable below 10 ‰.

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1) He described the species as Teredo diegensis Bartsch, but it is a synonymous form of Lyrodus pedicellatus (Quatrefages) after Turner (1966).

Salinities at the test localities in the present investigation were not significant for controlling both the occurrence and the dispersal of shipworms. Of course, there found a few exceptions, that is, the decline in the activity of shipworms was noticeable in Miyajima owing to the sudden fall of salinity. Consequently, water temperature is the most important factor for the activity of the animals: water temperature is the controlling agent of growth and reproduction because the optimum water temperature of each species appeared to influence the growing and spawning of shipworms (see Table 17 on page 49).

On the basis of the fact that some species such as *Bankia setacea* (Tryon) and *Nototeredo norvagica* (Spengler) are found only in cold waters and some such as *Bactronophorus thoracites* (Gould) and *Bankia bipennata* (Turton) are restricted to warmer waters, each species is adapted for different range of water temperature with the optimum temperature for its activity. That is well reflected by the pattern of the geographic distribution of each species in the world (Turner, 1966; Nair and Sarawathy, 1971).

In Japan, shipworms are active in growing and reproducing during warmer seasons (Murakami, 1958; Mawatari, 1958; Imai et al., 1950; Tsunoda and Nishimoto, 1972 and 1976). The rise of water temperature in the early summer apparently stimulated the adult shipworms to release larvae or gametes into the water. The settlement of shipworms generally began at water temperatures above 20°C in June, and terminated at the lower temperatures, though the range of water temperatures in which settlement occurred was varied with localities. A few shipworms could bore into wood even at temperatures of around 15°C or below it in Noto, Aioi, Naruto and Takahama. For example, at Naruto shipworms settled at temperatures ranging from 9.9° to 28.4° C. The duration of settlement also depended on localities.

Teredo navalis Linnaeus in the Atlantic coast of Canada had the optimum water temperature of 22.5°C (Anon., 1927). In Sweden, the species was most active at temperatures ranging from 15° to 25° C (Roch, 1932). Nelson (1928) found that Teredo navalis Linnaeus of Barnaget Bay, New Jersey began to expel the offsprings at 15°-16° C. Grave (1928) reported that the first spawning of the species was observed when the water temperature reached 11°-12° C in Woods Hole, Massachusetts. At Onagawa, spawning occurred first at 18° C in the early summer and ended in the late fall (Imai et al., 1950). Loosanoff and Davis (1963) who reared Teredo navalis Linnaeus in the laboratory showed that spawning occurred at temperatures of 14° C and higher, and that larvae were released at temperatures ranging from 16° to 20° C. Sullivan (1948) obtained the similar data that spawning might take place at about 15°C.

The larvae of Teredo navalis Linnaeus could not bore into wood at temperatures above 26° C or below 14° C. Furthermore, many were found dead at temperatures of both above 30° C and below 8° C (Imai et al., 1950). More recently, Culliney (1975) reported that specimens of the species released offsprings at temperatures ranging from 13° to 30°C in the laboratory.

On the contrary, the adults are known to survive a wide range of temperatures. Roch (1932) described that Teredo navalis Linnaeus could remain for some time at freezing water temperature of -1.4°C in Swedish water. Imai et al. (1944) showed that the larvae of Lyrodus pedicellatus (Quatrefages) had the optimum water temperatures of 15°-20°C with the potential range between 10° and 25°C. The effect of salinity and water temperature on the other species of shipworms should be referred to the review by Nair and Sarawathy (1971).

As discussed above, settlement of shipworms is affected greatly by the environmental factors, especially by water temperature, though no experimental evidence in the laboratory was not procured in the present investigations. In addition, the presence of attacked wood and the amount of wood available for shipworms as food are important. The results that the heavy infestation of shipworms was recorded in the sea water log storage area at Takahama well demonstrate it. The larvae are continuously produced by the parents in previously attacked timber, and they can find new habitat with ease if there is a lot of sound wood in the vicinity of attacked wood. Therefore, the removal of old riddled wood could be of great help for reducing and preventing the damage caused by shipworms.

II-4. Summary

Settlement of shipworms was determined by the regular monthly replacement of test panels or blocks at 14 localities along the coasts of Japan. Borer apertures on the wood surfaces were taken as the index of shipworm settlement.

Summing up the results, the following figure is obtained with the species present, and the range of water temperature and salinity in which settlement of shipworms was observed. The peak, if it is conspicuous, is marked by an asterisk (*) in the figure (Fig. 9). The dominant species at each locality is also circled.

In Japanese waters, the settlement of shipworms generally began at water temperatures above 20° C and terminated at the lower temperatures than those of beginning, though the range of water temperatures in which settlement occurred was varied with localities. At Naruto larval settlement began in June when water temperatures were over 20° C, and ended in December or January or February with temperatures of approximately 10° C.

The period of settlement was relatively long (usually from June to December) but depended mainly on water temperature and the amount of attacked wood at the tested sites. The peak of settlement generally coincided with rather the transition stage of water temperature in September or October when water temperature began to fall than the highest temperature in August. A few exceptions were noticed at Oppama and Tatoku Island where the number of borer apertures on the wood surfaces was quite small.

Locality	Month J	F	M	A	M	J	J	A	S	O	N	D	Shipworm sp.a)	Water Temp. (°C)	Salinity (‰)
Onagawa													1	18.7 — 21.2	
Sado													1,4		
Oppama													1	17.0 — 26.0	
Aburatsubo													1,5		
Noto													1,2,3	10.5 — 26.0	33 — 37
Tatoku Is.													1,3,4	17.9 — 29.1	
Aioi													1	9.2 — 29.0	25.7 — 28.4
Uno													1,3		
Miyajima													1,3	20.0 — 26.0	29.1 — 34.3
Shimonoseki													1,3	15.7<	30 — 34
Nagasaki													1,3	16.0 — 26.0	
Naha													2,3,4		
Naruto													1,2,3,5	9.9 — 28.4	32 — 34
Takahama													1,2,3,4,7	13.8 — 30.1	32 — 37

Fig. 9. Summarized data on monthly settlement of shipworms at 14 test localities along the coasts of Japan.

a) 1: Teredo navalis Linnaeus, 2: Teredo furcifera von Martens,
3: Lyrodus pedicellatus (Quatrefages), 4: Bankia carinata (Gray),
5: Bankia campanellata Moll and Roch, 6: Bankia bipennata (Turton),
7: Nototeredo edax (Hedley)

III. Pattern of Vertical Settlement of Shipworms at Takahama

The depth preference of marine wood borers is ecologically significant since the degree of attack on marine wooden constructions varies with the depth of water together with environmental factors and competition with fouling organisms (e.g. Atwood and Johnson, 1924; Johnson et al., 1936; Edmondson, 1942 and 1944; Mawatari, 1950; Mori, 1958; Sarawathy and Nair, 1969; Fung and Morton, 1976). Both limnorial borers and shipworms are significant for the destruction of marine wooden structures. However, only shipworms play an important role in the matter of the deterioration of the logs stored in the sea water storage sites (Trussell et al., 1956; Tsunoda and Nishimoto, 1972).

Only a few papers have dealt with the pattern of vertical settlement of shipworms (e.g. Johnson, 1918; Watson, et al., 1936; Edmondson, 1944; Owen, 1953; Nair, 1966). They showed that the intensity of shipworm attack generally increased with depths in shallow waters (e.g. Kofoid et al., 1927; Edmondson, 1942; Quayle, 1953).

The sea water log storage areas are usually established in shallow waters. If the former results are true for the sea water log storage areas, sunken logs which are present inevitably at the bottom in the storage areas may help shipworms go downwards, and finally contribute to the reproduction of shipworms. Therefore, it is necessary to investigate the pattern of vertical settlement of shipworms in the sea water log storage site at Takahama, Fukui Pref.

III-1. Materials and Method

The investigations were carried out at test station B in the log storage area, Takahama, Fukui Pref. (see Fig. 8 on page 58) for 2 years from June, 1975. Water depth at the test station is around 23 m.

A monthly test string consisted of Scotch pine (*Pinus sylvestris* Linnaeus) test blocks (4 x 4 cm in section and 30 cm in length) connected by a rope and was submerged vertically from the floating structure at regular intervals of 1 m from 2 m below the water surface to the bottom level so that the deepest test block was situated at just 20-30 cm above the mud line. The test string was renewed every month to examine the monthly settlement of shipworms. After removal of test blocks, they were cleaned off fouling organisms and debris, and then subjected to the close inspection of borer apertures on the surfaces of the blocks under a binocular stereoscopic microscope. Therefore, the number of borer punctures was taken as the single criterion of shipworm settlement.

The data on the monthly settlement at the test site was applied to the results at 0.3, 0.8 and 1.3 m levels.

Water temperatures and salinities at different depths were not measured but only at the surface level.

III-2. Results and Discussion

III-2-1. Series I during the period from June, 1975 through May, 1976

Shipworm attack continued for 9 months from June to February with a marked peak in September. The number of borer punctures on the wood surfaces was few in June, January and February. Particularly in February, only 2 borer holes were detected on the horizontal upper surface of a test block immersed at 23 m depth. Unfortunately the test string was lost in November.

The heavier infestation generally occurred at deeper levels (Figs. 10 and 11) as demonstrated at other localities in the world: Manati Bay, Cuba (Hobby, 1918; Johnson, 1918), San Francisco Bay (Kofoid et al., 1927), Beaufort, North Carolina (McDougall, 1943), Loch Ryan, Scotland (Owen, 1953), Ladysmith Harbor, British Columbia (Quayle, 1953), Shirahama, Wakayama Pref. (Mori, 1958), Cochin Harbor, India (Nair, 1966), Monterey Bay, California (Haderlie and Mellor, 1973).

In September the intensity of shipworm infestation typically incresed with increase in depth down to the bottom (Fig. 11). The extent of infestation increased abruptly with increasing depth down to 12 m and 10 m levels in August and October respectively. And it was followed by the sharp decrease at deeper levels up to approximately 20 m depth, and then it increased slightly as shown in Fig. 10. The resultant peaks of shipworm infestation along the water column were observed at around 10 m depth in August and October. In July and December slight shipworm attack was found, and

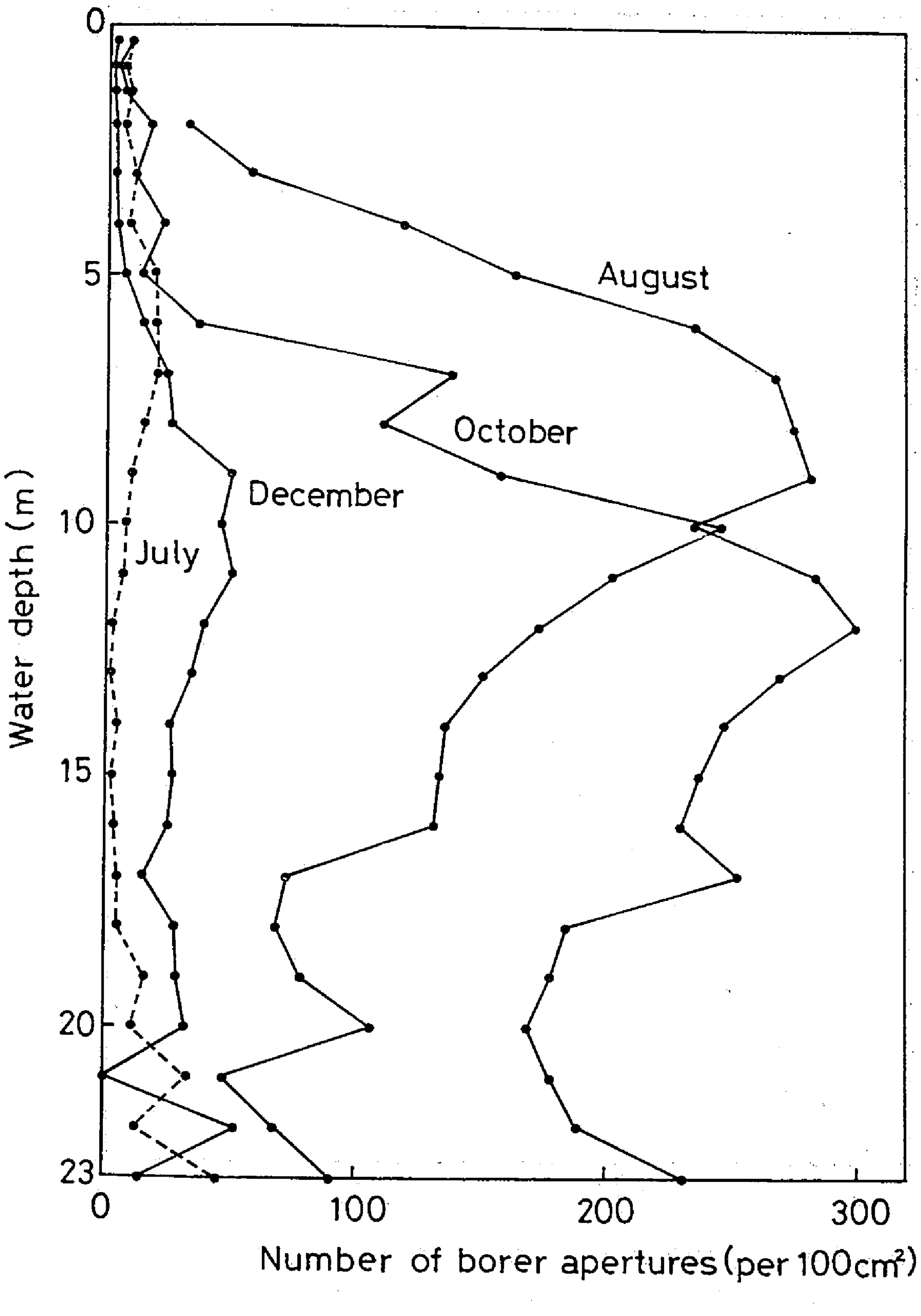

Fig. 10. Patterns of vertical settlement of shipworms in July, August, October and December, 1975.

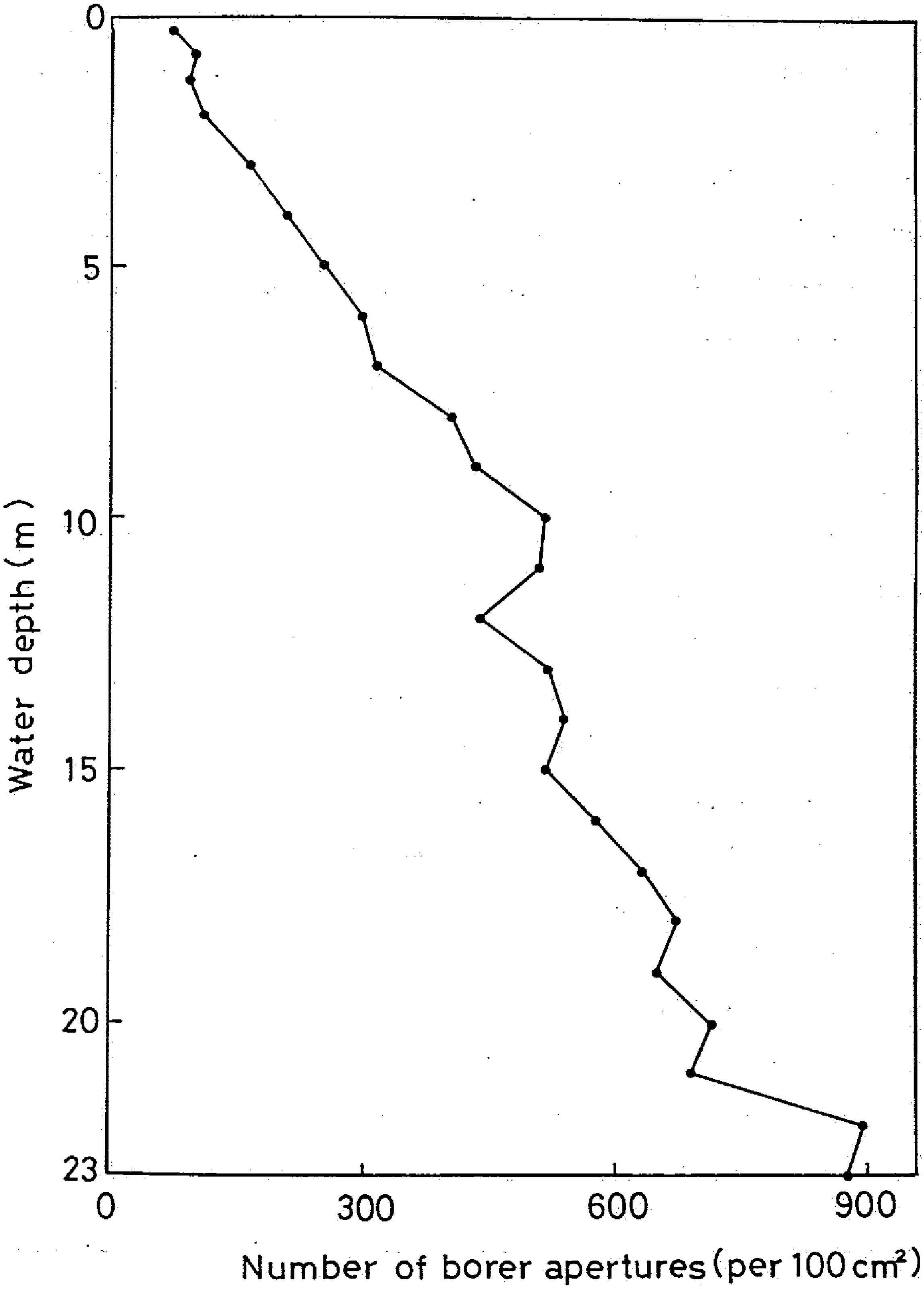

Fig. 11. Pattern of vertical settlement of shipworms in September, 1975.

the number of borer apertures relatively showed the even vertical distribution from 0.3 m depth to 23 m depth.

Pattern of vertical settlement in September would be well explained by the effect of light: the maximum infestation is expected to occurr in the dim regions. The larvae of Teredo pedicellata de Quatrefages[1)] preferably settled and bored into wood under conditions of illumination of 166 ft candles (Isham et al., 1951). In addition, the larvae tend to sink downwards whenever ciliary activity ceases, which is due to the higher specific gravity of the animals than that of sea water (Isham and Tierney, 1953). It, therefore, possibly takes part in the tendency of vertical settlement in the month. The larvae can actively move horizontally and vertically, though their vertical motion becomes a matter of importance in considering the different patterns of vertical settlement. They are also transported by the current of water and the passive movement of water caused by the passage of boats. Consequently, the larvae would tend to move either upwards or downwards to look for the more favorable zone along the water column.

However, the results in August and October did not testify to the above explanations: 2 peaks of shipworms were observed. The increase in the extent of shipworm infestation observed from 20 m depth to the deepest level would

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1) Isham et al. called specimens which they studied Teredo pedicellata de Quatrefages. But that was misidentification. The species is Teredo bartschi Clapp after Turner, 1966.

be reflected by the abundance of shipworms mainly due to the presence of riddled sunken logs at the bottom.

Examination of the surface-preference of shipworms showed that the animals preferably settled on the horizontal surfaces at all the depths, particularly at deeper levels. In August the ratios of borer's population on the horizontal surfaces to the total number of shipworms found on the overall surfaces of blocks were: 55 % at 2 m depth, 62 % at 6 m depth, 68 % at 10 m depth, 76 % at 14 m depth, 70 % at 18 m depth and 85 % at 23 m depth. The ratios of shipworm population on the horizontal surfaces in July, September, October and December are tabulated below (Table 24).

Table 24. Ratios of shipworm population (%) on the horizontal surfaces to the total number of shipworms found on the overall surfaces of the blocks at selected depths.

Depth (m)	Month			
	July	Sep.	Oct.	Dec.
2	42	57	53	20
6	70	58	56	53
10	63	73	78	59
14	44	64	58	61
18	60	79	74	80
23	85	81	72	64

Of the horizontal surfaces, the upper surfaces were infested more severely than the lower ones. This tendency was also conspicuous in deeper regions as shown in Table 25. The tendency of which the upper surfaces suffer severer infestation than any other surfaces and the number of borers settling on the upper surfaces generally increases proportionally with water depths would demonstrate the settling behavior of shipworms that they selectively settle on wood when they go downwards.

Table 25. Ratios of shipworm population (%) on the upper surfaces to the total number of shipworms found on the overall surfaces of the blocks at selected depths.

Depth (m)	July.	Aug.	Month Sep.	Oct.	Dec.
2	33	8	23	22	10
6	53	32	38	38	25
10	48	48	67	63	52
14	22	63	52	52	55
18	53	62	69	65	75
23	75	78	75	66	53

III-2-2. Series II during the period from June, 1976 through May, 1977

Shipworm attack was observed for 8 months from June to January. A remarkable peak was recorded in August when monthly mean water temperature at the surface level was the highest (28.7°C) in the year. Monthly mean water temperatures in Series II were lower by 0.5°-3.1°C than those in Series I.

The heaviest infestation approximately occurred in the deepest zone as shown in Figs. 12 and 13. The number of borers increased with increase in depth down to 5-10 m regions. The surface zone between 0.3 and 2 m depths was very slightly attacked by the animals (fewer than 20 apertures per 100 cm^2). In August, however, much severer attack emerged even at 0.8 m depth, and the extent of infestation increased almost proportionally with water depth. When comparing this with the heaviest month, September in Series I, the pattern of vertical settlement in August, 1976 would show the direct proportion to water depths.

Patterns of monthly vertical settlement of shipworms in Series II are figured in Figs. 12 and 13.

The horizontal surfaces suffered severer infestation than the vertical ones as shown in Table 26, but the ratios were comparatively lower than those in Series I. The upper areas of the horizontal surfaces were generally infested more severely than the lower and lateral surfaces (Table 27).

Table 26. Ratios of shipworm population (%) on the horizontal surfaces to the total number of shipworms found on the overall surfaces of the blocks at selected depths.

Depth (m)	Month						
	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
2	0	44	53	64	50	0	0
6	67	55	60	71	40	50	25
10	50	56	64	61	57	59	0
14	60	57	62	56	66	48	33
18	90	53	63	60	63	48	25
23	82	67	62	46	60	73	50

Though the pattern of vertical settlement may possibly be affected by illumination (Isham et al., 1951; Nagabhushanam, 1959), water temperature gradient with depths obviously restricts the vertical distribution of shipworms (Norman,

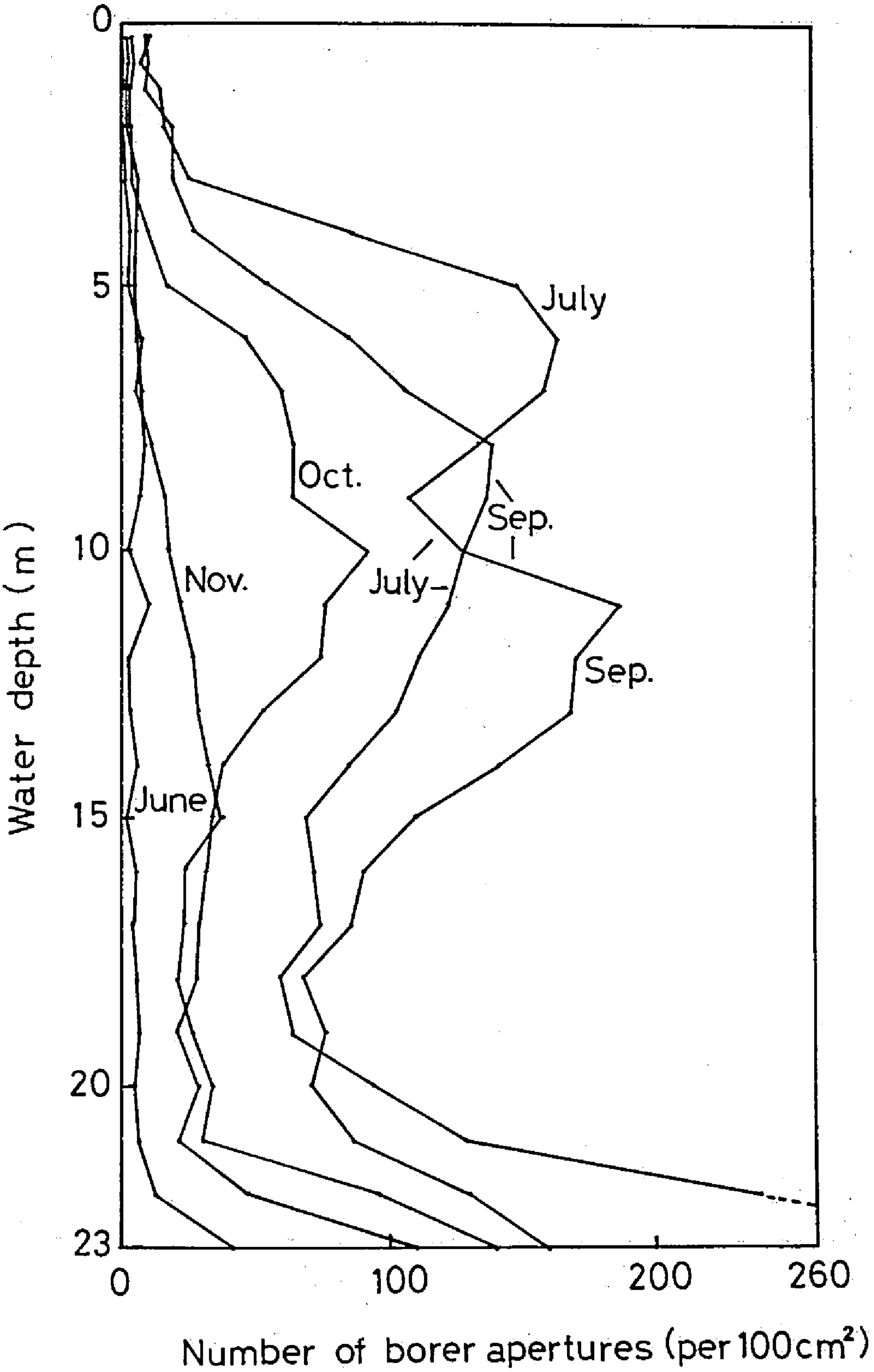


Fig. 12. Patterns of vertical settlement of shipworms in June, July, September, October and November, 1976.

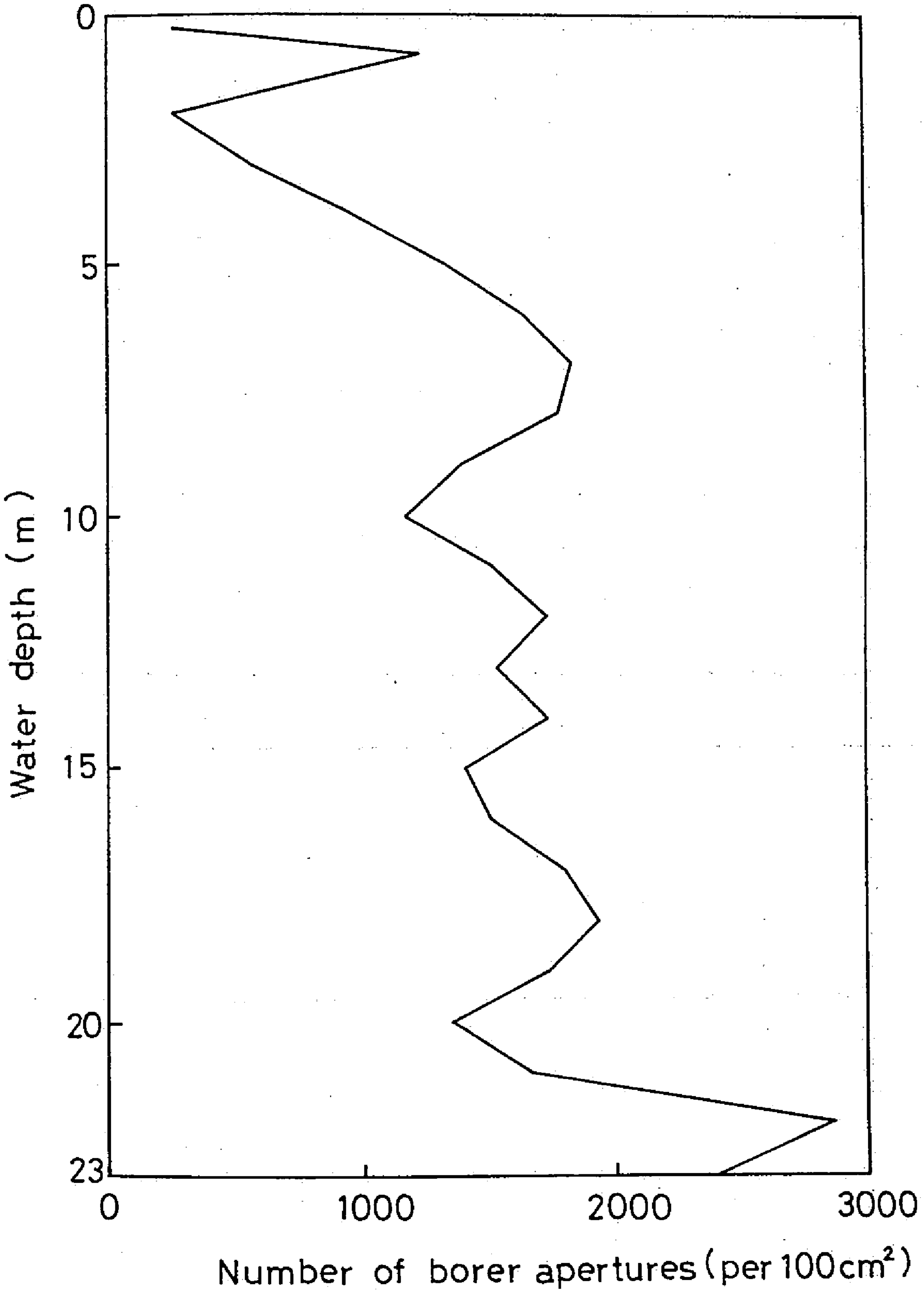


Fig. 13. Pattern of vertical settlement of shipworms in August, 1976.

1976). Therefore, the shipworms would be liable to move to the favorable light and temperature zones. For instance, the shipworm larvae are likely to concentrate on the wood at the surface level during the night, whereas they tend to settle on wood at deeper levels in the daytime (Nair and Sarawathy, 1971). Combination of these factors could produce the different types of monthly vertical settlement of shipworms as indicated in the present investigation.

Table 27. Ratios of shipworm population (%) on the upper surfaces to the total number of shipworms found on the overall surfaces of the blocks at selected depths.

Depth (m)	June	July	Aug.	Month Sep.	Oct.	Nov.	Dec.
2	0	16	26	51	29	0	0
6	60	45	47	62	29	35	0
10	67	49	42	53	30	34	0
14	61	40	44	48	40	41	17
18	86	48	54	34	54	25	0
23	74	50	55	30	37	55	13

Based on the results of Series I and II, the patterns of monthly vertical settlement of shipworms are assorted into the following 4 types:

(1) The intensity of infestation increases with increase in water depth so that the peak is recorded at the deepest region --- September, 1975 and August, 1976.

(2) The heaviest infestation, as same as the above, is observed at the deepest level with the second peak at approximately 10 m depth --- July and October, 1976.

(3) The heaviest infestation is observed at about 10 m depth; the extent of infestation increases in proportion to depths down to 10 m level and then decreases adversely, but rises again at depths between 20 m and 23 m --- August and October, 1975 and September, 1976.

(4) The infestation occurs very slightly and relatively evenly along the water column --- June, July and December, 1975 and June, November and December, 1976.

The heaviest-infested months, September, 1975 and August, 1976 truly belong to the type (1). And the months before and after the severest months undoubtedly represent 2 peaks at around 10 m and 23 m levels, belonging to the type (2) or (3). In those months which belong to the types (1), (2) and (3), the rate of attack on wood is significantly high without any exception as discussed in the later part.

As the results demonstrated that the shipworms can locomote vertically throughout the depths from the surface to the bottom, it is consequently important to remove not only the riddled floating wood but also the sunken logs especially in July, August, September and October for the purpose of reducing shipworm attack. This is principally significant for such the case of log storage area as the test site in the present investigation.

III-3. Summary

Test wood blocks (Pinus sylvestris Linnaeus) were suspended vertically in the sea water log storage area at Takahama, Fukui Pref., as the blocks were at 0.3, 0.8 and 1.3 m below the water surface and at regular intervals of 1 m from 2 m to the bottom level (about 23 m). The blocks were removed and replaced every month to examine the monthly vertical settlement of shipworms on the surfaces.

The heavier settlement was generally observed in deeper regions, particularly at the bottom. The patterns of monthly vertical settlement of shipworms on wood surfaces are divided into 4 types:

(1) The intensity of settlement of shipworms increases proportionally with water depth so that the maximum settlement is recorded at the deepest level (23 m depth) --- e.g. September, 1975 and August, 1976.

(2) The heaviest settlement, as same as the above, is observed at the deepest level with the second peak at about 10 m depth --- e.g. July and October, 1976.

(3) The heaviest settlement is recorded at approximately 10 m depth; the extent of settlement increases in proportion to water depth down to 10 m level and then decreases adversely, but rises again at depths between 20 m and 23 m --- e.g. August and October, 1975; September, 1976.

(4) The settlement occurs very slightly and relatively evenly along the water column --- e.g. June, July and December, 1975; June, November and December, 1976.

Wood blocks submerged in September, 1975 and August,

1976 suffered the heaviest infestation of shipworms and represented the pattern of vertical settlement of type (1). The months before and after the severest months obviously belonged to the type (2) or (3).

The effect of light intensity and water temperature gradient with depths would partly account for the different patterns of monthly vertical settlement of shipworms. And the active vertical locomotion of shipworms might help shipworms concentrate at deeper levels.

IV. Growth Rates of Shipworms, *Teredo navalis* Linnaeus at Naruto

Difficulties in determining the rates of growth of shipworms are due to the fact that the shipworms are hidden in their wood habitat just after initial boring. Formerly test panels infested with shipworms of known age were periodically sectioned to measure body length, diameter of burrow and burrowing volume, but this method could not follow the same individuals afterwards. Kofoid and Miller (1927) determined the rates of growth of *Teredo navalis* Linnaeus and *Bankia setacea* (Tryon) in San Francisco, California by measuring the size of burrows in Douglas fir test blocks exposed for known periods. They reported the average rates ranging from 1.0 cm per month for 6 weeks old specimens to 2.8 cm per month for 14 weeks old spcimens of *Teredo navalis* Linnaeus, and from 2.3 cm per month for 6 weeks old specimens to 6.3 cm per month for an 8 months old individual of the latter species. And they estimated the normal rate of growth of *Teredo navalis* Linnaeus over a period of months was approximately 2 cm per month, and 4.7 cm for *Bankia setacea* (Tryon). Johnson and Miller (1935), using the similar technique, reported an average rate of 1 cm increase in length per month for *Bankia setacea* (Tryon) at Friday Harbor, Washington. Grave (1928) showed the measurements of the lengths of burrows of *Teredo navalis* Linnaeus of specified age at Woods Hole, Massachusetts: 0.35 to 0.5 in 23 days (July 16 to August 8), 50 to 57 mm in 46 days (July 16 to September 1), 100 to 120 mm in 72 days (June 22 to September

3), and 250 to 400 mm in one year (July, 1923 to July, 1924). The rate of growth of the same species in North Carolina was 10 to 30 mm during the period from May to January (Richards, 1943). Imai et al. (1950) succeeded in rearing *Teredo navalis* Linnaeus in a large outdoor tank without controlling water temperature, and measured body length, shell width and number of ridges at intervals of 4 to 10 days for 60 days. The average lengths of the animals after initial penetration were as follows: 0.45 mm in 10 days, 0.67 mm in 15 days, 2 mm in 20 days, 10.4 mm in 40 days and 50.5 mm in 60 days.

There are some other growth studies based on the classic method in which measurement is made by periodic sectioning of test panels: Sigerfoos (1908) for *Bankia gouldi* (Bartsch), Kramp (1927) and Dons (1940) for *Psiloteredo megotara* (Hanley), Johnson et al. (1936) for 3 Australian shipworms, Nair (1960) for *Bankia carinata* (Gray), Nagabhushanam for *Bankia campanellata* Moll and Roch (1959a) and *Teredo furcifera* von Martens (1961), and Harada (1958) for 4 Taiwanese shipworms.

The X-ray technique can, however, satisfactorily be used for the determination of the rates of growth. The advantage of the method is that it does not destroy the wood habitat and the animals and renders possible the repeated measurement of individuals over a long period. The possibility of the X-ray technique for the study of the growth rates of shipworms was first indicated in 1924 (Atwood and Johnson, 1924).

Several investigators have so far employed the X-ray technique for growth studies: Ralph and Hurley (1952) and Hurley (1959) for *Bankia australis* (Calman) in New Zealand, Trussell et al. (1956) and Quayle (1956, 1959) for Bankia setacea (Tryon) in British Columbia, Canada, and Haderlie and Mellor (1973) for Bankia setacea (Tryon) in California.

The technique can also be applied for the estimation of the progressive shipworm attack on untreated and treated wood with the length of immersion (e.g. Oliver, 1959; Fougerousse, 1968; Fougerousse and Deshamps, 1968; Fougerousse and Gueneau, 1971; Fougerousse and Lucas, 1970, 1976).

In the present investigation the X-ray technique was employed for the determination of the growth rates of shipworms, Teredo navalis Linnaeus, a representative species in Japanese waters as well as in other temperate parts of the world.

IV-1. Materials and Method

The investigation was carried out at Uchinoumi, Naruto, Tokushima Pref. (34°12'30"N, 134°36'27"E).

The rates of growth of shipworms (Teredo navalis Linnaeus) were estimated directly from the lengths of burrows on the X-ray photographs taken by using Softex Type K or EMB and Fuji Softex films. Length measurements included 3 series from August 19, 1973 as follows:

Series I --- August 19, 1973 - May 19, 1974

Series II -- September 10, 1974 - September 10, 1975

Series III - September 10, 1975 - September 10, 1976

Douglas fir (Psedotsuga menziesii (Mirb.) Franco) blocks which were covered with plastic sheets except for the ends were submerged in the sea from the experimental raft, as the blocks were between 30 and 100 cm below the water surface. Shipworm attack was therefore restricted only to the ends, and the animals had to grow parallel to the grain.

The size of blocks was 2 x 6 x 30 cm in Series I, and was changed to 2 x 6 x 28 cm in Series II and III simply because X-ray photographs could be taken more conveniently from this size.

The blocks were removed at monthly intervals for X-raying at distance of 70 cm with 40 KV and 3 mA for 15 seconds, and then returned to the water to permit continuous development of the animals.

IV-2. Results and Discussion

All the specimens examined here were the commonest shipworm species Teredo navalis Linnaeus.

IV-2-1. Series I

Of 3 test blocks submerged on August 19, 1973 and first X-rayed on October 22, 1973 (64 days after immersion in the sea), only one block was infested with 2 shipworms (A and B in Table 28). Their rates of growth were repeatedly followed. On November 19, another specimen (C in Table 28) appeared on the X-ray photograph, and measured 4 mm long. In addition, one more specimen (D in Table 28) was found on January, 1974. This animal possibly succeeded in penetrating into the test block in late December or early January when water temperatures were below 14° C.

Table 28. Body lengths (mm) of shipworms at Naruto during the period from August 19, 1973 to May 19, 1974.

Specimens	Oct.22 1973	Nov.19	Dec.19	Jan.19 1974	Feb.19	Mar.19	Apr.19	May19
A	99	155	194	220	241	252	270	Dead
B	97	152	180	195	207	223	241	Dead
C	-	4	9	17	25	31	43	59
D	-	-	-	3	8	12	18	29
Water temp. (°C)*	23.6	19.6	13.9	9.0	8.3	9.5	14.8	18.7
Salinity**				32-34				

*: Monthly mean water temperature at the surface level.

**: Salinity ranged between 32 and 34 ‰ through the investigation.

As expected, all the specimens grew almost straight along the grain, and the older ones (A and B) attained a length of about 200 mm within 5 months. They, however, were found dead on May 19, 1974 at the age of 9 months as shown by the deposition of the valves and pallets on the X-ray photograph. The younger specimens C and D had grown up to 59 mm and 29 mm respectively until May 19 when they were at least 6 months and 4 months old (see Table 28). Consecutive growth of the animals is shown in Plates 1-A and 1-B.

On the basis of the monthly increment of body length, the rates of growth were high during the period with high water temperatures above 20°C as shown in Fig. 14, and dropped remarkably below 15°C although the animals continued burrowing. Moreover, each individual that showed a similar growing pattern for the first few months as seen in A and B, gradually changed the pace of burrowing (see Plates 1-A and 1-B), and attained different body length at last.

IV-2-2. Series II

Six test blocks were submerged on September 10, 1974. The 1st X-ray photographs of them taken on October 10, 1974 revealed an infestation of shipworms in 5 test blocks. Nine specimens were distinguished and their rates of growth were followed; the measurements showed average rates ranging from 13 mm for one month old specimens to 38 mm per month for 3 months old ones. Results of length measurements are shown in Table 29 together with average lengths. The largest specimen H and I were longer compared with the 2 specimens A and B of Series I at the same age. They extended

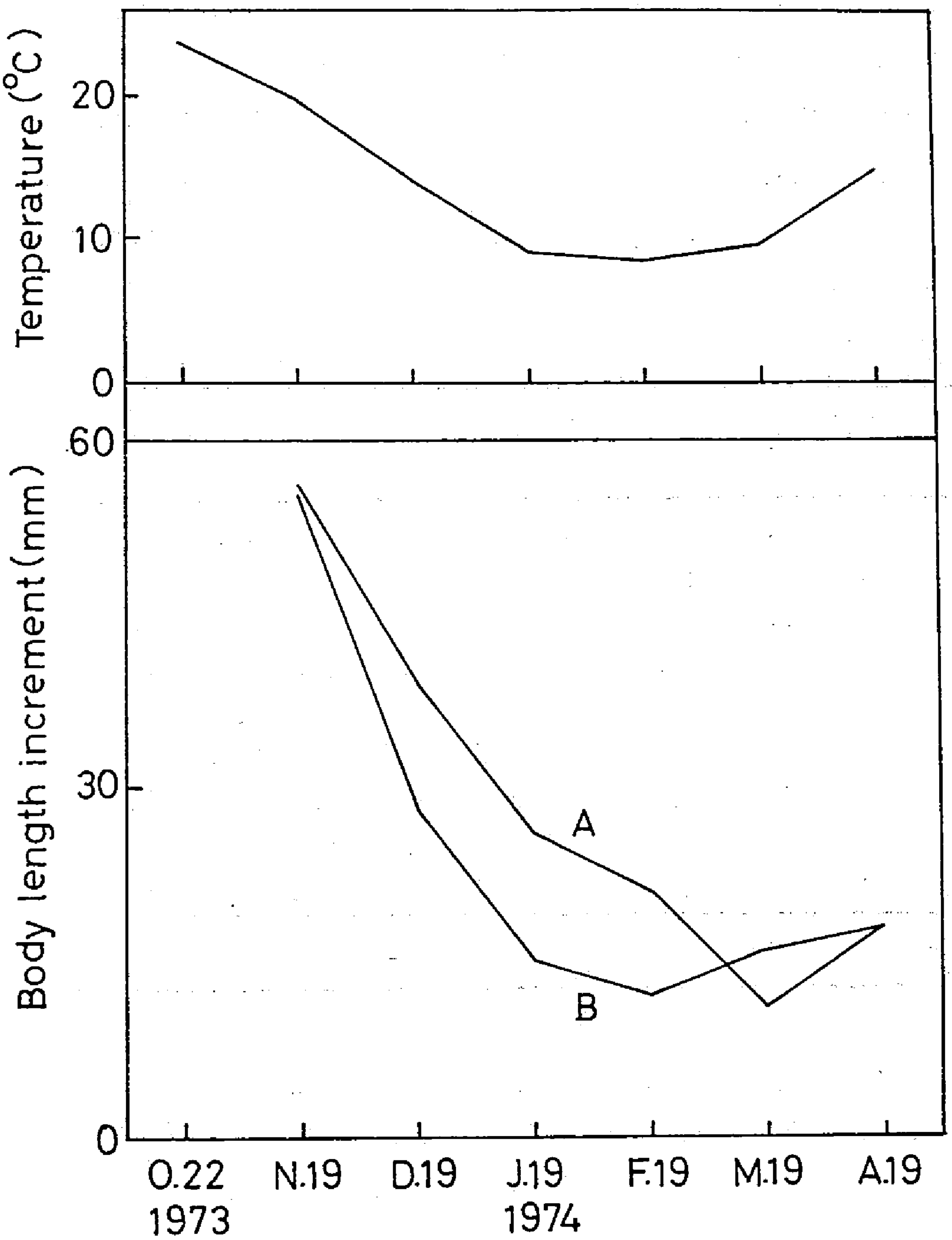


Fig. 14. Monthly body length increment of 2 specimens of *Teredo navalis* Linnaeus (A and B in Table 28) at Naruto.

their burrows over the whole length of a test block (28 cm) within 8 months.

Three animals which appeared on the X-ray photographs of November 10 were also measured and the results are tabulated below (Table 30). In Plates 2-A and 2-B, a series of X-ray photographs of a test block is given.

Table 29. Body lengths (mm) of shipworms at Naruto during the period from September 10, 1974 to July 10, 1975*.

Specimens	Oct. 10 1974	Nov. 10	Dec. 10	Jan. 10 1975	Feb. 10	Mar. 10	Apr. 10	May 10	June 10	July 10
E	3	32	66	88	90	100	108	Dead		
F	5	47	95	132	152	170	185	205	Dead	
G	17	51	104	126	142	155	171	200	247	**
H	21	104	173	209	232	248	271	280	**	
I	19	103	174	207	231	248	270	278	**	
J	33	115	132	149	164	174	196	200	**	
K	11	82	123	148	158	161	168	190	**	
L	4	21	43	64	81	93	112	144	**	
M	5	62	123	160	182	192	211	243	280	Dead
Average***	13	69	115	143	159	171	188	218	-	-
Water temp. (°C)****	24.3	19.2	14.3	10.9	8.8	10.3	14.0	17.5	21.9	25.4

*: Test blocks were X-rayed until September 10, 1975.

**: Impossible to measure body lengths because of crowding or complicated turning of the burrows.

***: Average body length (mm) of the animals.

****: Monthly mean water temperature at the surface level.

Table 30. Body lengths (mm) of 3 specimens which appeared first on November 10, 1974 at Naruto.

Specimens	Nov. 10 1974	Dec. 10	Jan. 10 1975	Feb. 10	Mar. 10	Apr. 10	May 10	June 10	July 10
N	30	88	134	165	190	227	257	*	
O	26	82	120	142	156	178	208	255	*
P	30	79	121	148	173	200	224	273	*
Average**	29	83	125	152	173	202	230	-	-

*: Impossible to measure body lenghts because of crowding or complicated turning of the burrows.

**: Average body length (mm) of the animals.

IV-2-3. Series III

Seven specimens of shipworms in 3 test blocks submerged on September 10, 1975 were detected on the first X-ray photographs taken on October 10, 1975.

On the basis of the results of length measurements in Table 31, the average rates ranged from 12 mm for one month old specimens to 55 mm per month for 3 months old ones. The largest monthly growth, however, was obtained in the 2nd month (over 80 mm on an average) as true for Series II, though the animals of Series III grew somewhat more rapidly than those of Series II. The largest specimen T reached 280 mm in length within just 5 months. A series of X-ray photographs of a test block is shown in Plates 3-A and 3-B.

As shown in Table 32, the average growth rates per month are statistically estimated from all the results despite the great variations observed among individuals.

Table 31. Body lengths (mm) of shipworms at Naruto during the period from September, 1975 to July 10, 1976*.

Specimens	Oct. 10 1975	Nov. 10	Dec. 10	Jan. 10 1976	Feb. 10	Mar. 10	Apr. 10	May 10	June 10	July 10
Q	13	92	153	200	229	230	241	260	264	Dead
R	14	108	161	207	241	267	**			
S	11	78	143	183	207	232	252	**		
T	10	110	191	247	280	Dead				
U	8	71	135	173	188	202	Dead			
V	17	113	188	239	Dead					
W	10	97	181	245	**					
Average***	12	96	165	212	233	-	-	-	-	-
Water temp. (°C)****	23.9	19.2	15.1	9.9	9.6	11.1	13.4	17.9	21.4	24.4

*: Test blocks were X-rayed until September 10, 1976.

**: Impossible to measure body lengths because of crowding or complicated turning of the burrows.

***: Average body length (mm) of the animals.

****: Monthly mean water temperature at the surface level.

Table 32. Average rates of growth (mm) per month compiled from the results of Series I, II and III.

Age (month)	1	2	3	4	5	6	7	8
Average growth per month (mm)	13	44	48	46	40	33	31	30

The results obtained herein appear to coincide with Grave's (1928) on the whole, but not with Imai and other's (1950). The specimens never reached 400 mm in the present investigation, whereas the largest ones had reached 250-400 mm within one year at Woods Hole, Massachusetts, U.S.A. (Grave, 1928). It may possibly depend on the size of the test blocks and/or the duration of the test.

<u>Teredo furcillatus</u> Miller (= a synonym of <u>Teredo furcifera</u> von Martens after Tuener, 1966), allied to the tested materials here, showed that the maximum increment of body length (29 mm) corresponded to the highest water temperature of 30.9° C in May. And all the animals were dead in October when the water temperature was still high (30° C) enough for surviving. That was due to the sudden drop of salinity from about 26.5 ‰ to 4.63 ‰ (Nagabhushanam, 1961).

Accordingly, the growth of shipworms should be considered by the interrelation of environmental factors such as salinity and water temperature. Salinities at Naruto remained at 32-34 ‰ throughout the investigations and resulted in an insignificant effect on the growth of shipworms.

The growth of shipworms, however, is undoubtedly affected by water temperatures, and additionally by the rate of crowding and the difference of activities among individuals. The mere values of water temperature influence shipworms' growth, but the fluctuations of the temperature throughout the year seem to play the more important role in the boring activity of the animals. Dependence of shipworm growth on water temperature is also demonstrated by the abrupt decrease in winter with temperatures below 10° C.

The decrease in growth with the fall of water temperatures in winter time (see Tables 28, 29, 30 and 31), and the fact that individuals separately keep lengthening their burrows would mean that the growth rates vary not only seasonally but also individually (see specimens C and D in Table 28, and N, O and P in Table 30).

Favorable temperatures for shipworm boring consequently seem to lie between 15° and 25°C at the test site. Moreover, the rapid growth for the first few months during September, October, November and December testifies this temperature preference of the shipworms as shown in Fig. 15.

As the shipworms were forced to grow parallel to the grain, which could be the most favorable condition for their boring, they grew more quickly than those who usually have to across the grain. During his inspections the author has rarely found shipworms longer than 300 mm in attacked logs stored in sea water along the Japanese coast lines for 6 months because the individuals cannot burrow straight along the grain undisturbed by others.

When the growth rates of <u>Teredo navalis</u> Linnaeus are compared with other shipworm species, such as <u>Bankia setacea</u> (Tryon) investigated by Quayle (1959) and Haderlie and Mellor (1973), the latter, possibly prefering a different water temperature, shows higher rates of growth than the former. The difference in growth rates of these 2 species is probably species-specific.

As shown above, the body lengths of shipworms are not directly determined by the age, but the animals can reach sexual maturity within a relatively short time. The youngest <u>Teredo navalis</u> Linnaeus which can spawn are just 6 weeks old, and 38 mm in length (Grave, 1928). Therefore, we have to take the removal of attacked timber into consideration as a possibility to prevent deterioration. That is particularly true for the sea water log storing areas which are located along the coasts of Japan seriously infested with shipworms (see part I). Most of the specimens observed were dead before they became 10 months old. And only a few such as G in Table 29 were still alive even at the end of observation. The life span, consequently, is not simply determined but many are likely to live until the age of 6 months. Some can extend their life spans to one year or longer if the conditions are favorable for survival.

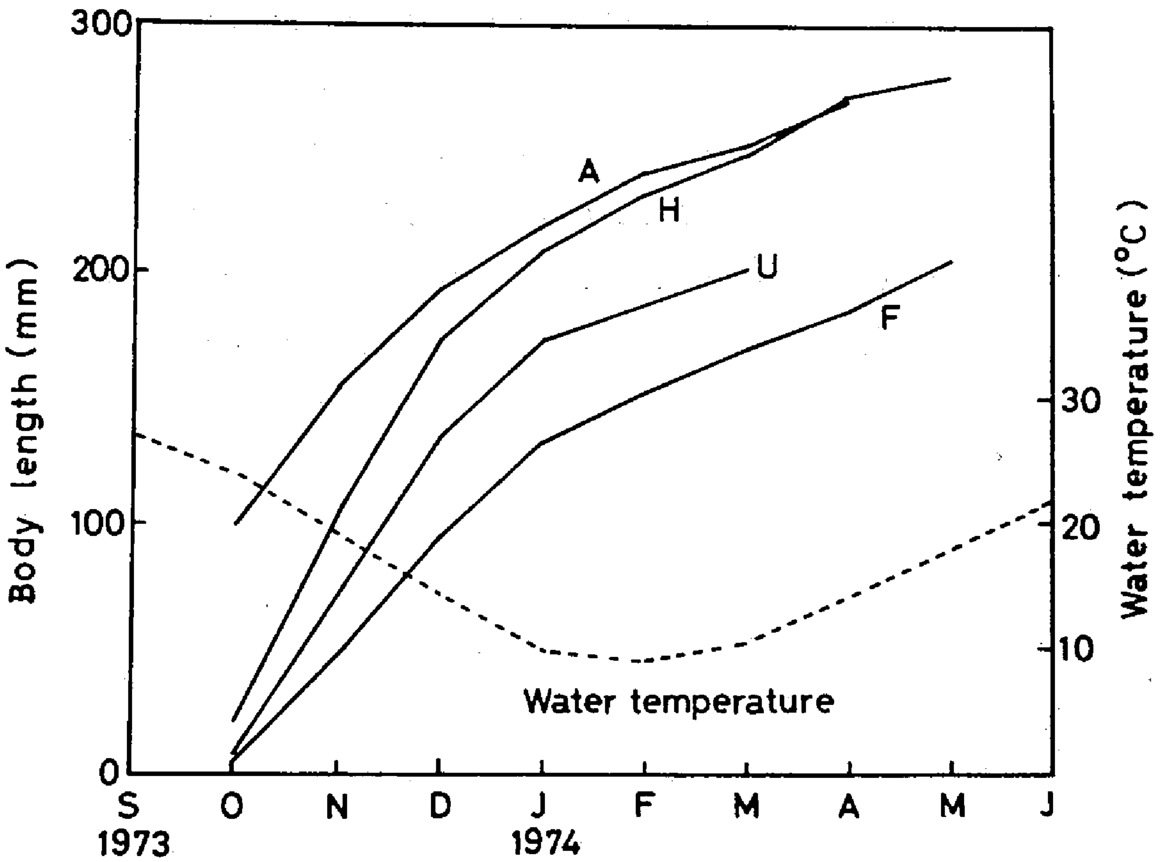


Fig. 15. Increase in body lengths of the 4 selected specimens (A, F, H and U) at Naruto.

IV-3. Summary

The growth rates of *Teredo navalis* Linnaeus boring into Douglas fir test blocks were determined directly from the lengths of burrows on X-ray photographs. The rates of growth varied with water temperatures and the extent of crowding. The average rates ranged from 13 mm per month for one month old specimens to 48 mm for 3 months old ones. Some specimens consequently exceeded 200 mm in length within 5 months. The optimum water temperatures for the growth of *Teredo navalis* Linnaeus seemed to lie between 15° and 25°C as evident from the rapid growth at the test site (34°12′30″ N, 134°36′27″E) in September, October, November and December, and the decline of growth in the winter season with water temperatures below 10°C.

The life span of shipworms is not simply determined, but many are likely to live until the age of 6 months. Some can obviously extend their life spans to one year or longer if the conditions are favorable for survival.

Plate 1-A

Consecutive growth of shipworms, *Teredo navalis* Linnaeus at Naruto. Douglas fir test block (2 x 6 x 30 cm) was submerged in the sea on August 19, 1973.

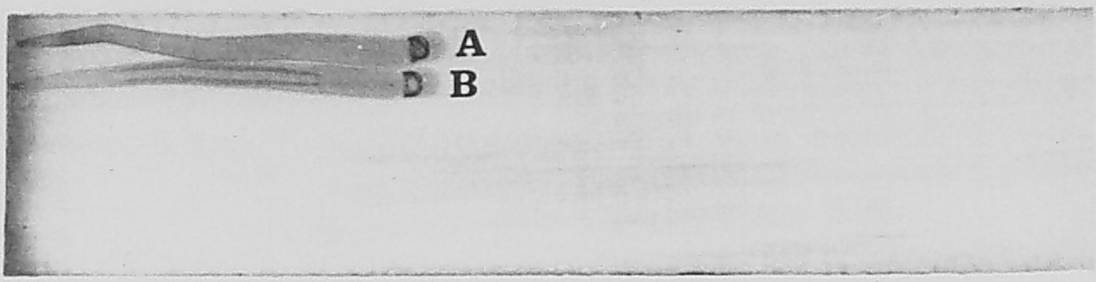
1: About 2 months after submergence; 2 specimens A and B are seen (body length -- A=99 mm; B=97 mm).

2: Three months after submergence; specimen C first appeared (body length -- A=155 mm; B=152 mm; C=4 mm).

3: Four months after submergence (body length -- A=194 mm; B=180 mm; C=9 mm).

4: Five months after submergence; another specimen D appeared (body length -- A=220 mm; B=195 mm; C=17 mm; D=3 mm).

Plate 1-A



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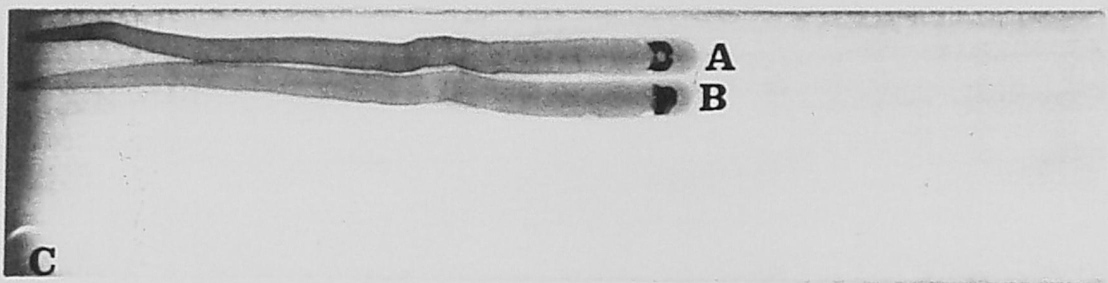

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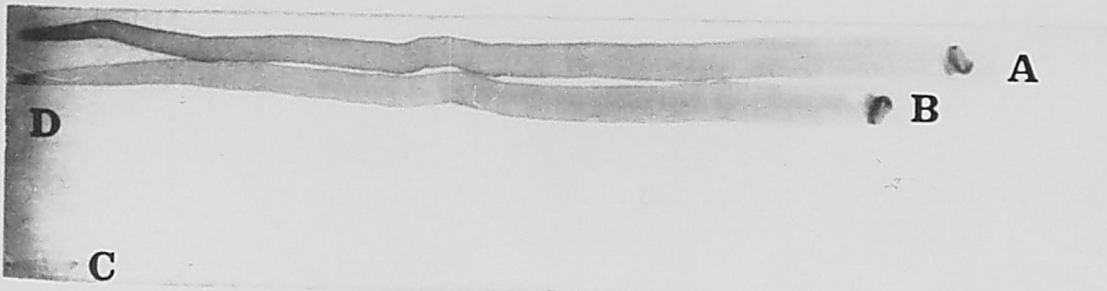

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Plate 1-B

Consecutive growth of shipworms, _Teredo navalis_ Linnaeus at Naruto. Douglas fir test block (2 x 6 x 30 cm) was submerged in the sea on August 19, 1973.

5: Six months after submergence (body length -- A=241 mm; B=207 mm; C=25 mm; D=8 mm).

6: Seven months after submergence (body length -- A=252 mm; B=223 mm; C=31 mm; D=12 mm).

7: Eight months after submergence (body length -- A=270 mm; B=241 mm; C=43 mm; D=18 mm).

8: Nine months after submergence (body length -- A, B=dead; C=59 mm; D=29 mm).

Plate 1-B

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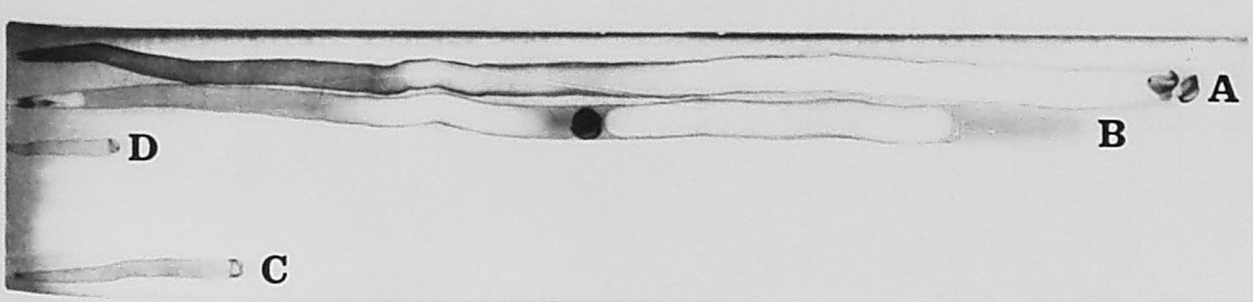

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Plate 2-A

Consecutive growth of shipworms, *Teredo navalis* Linnaeus at Naruto. Douglas fir test block (2 x 6 x 28 cm) was submerged in the sea on September 10, 1974.

1: One month after submergence.

2: Two months after submergence.

3: Three months after submergence.

4: Four months after submergence.

5: Five months after submergence.

1

2

3

4

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Plate 2-B

Consecutive growth of shipworms, *Teredo navalis* Linnaeus at Naruto. Douglas fir test block (2 x 6 x 28 cm) was submerged in the sea on September 10, 1974.

6: Six months after submergence.

7: Seven months after submergence.

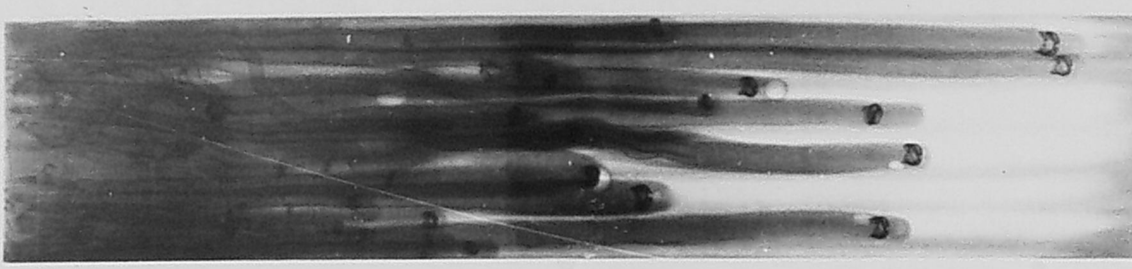
8: Eight months after submergence.

9: Nine months after submergence.

10: Ten months after submergence.

Plate 2-B

6



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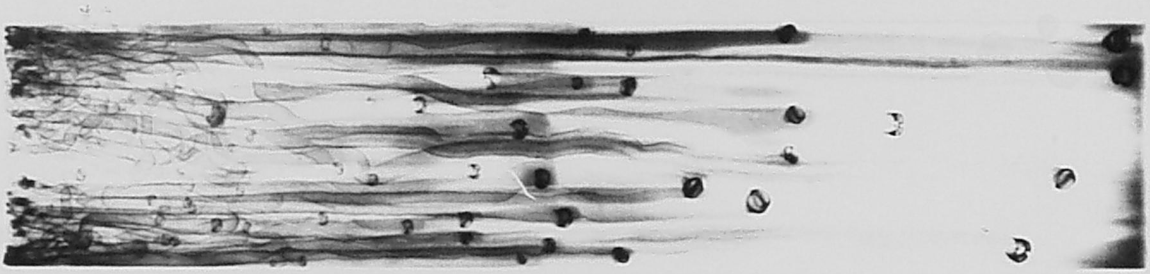

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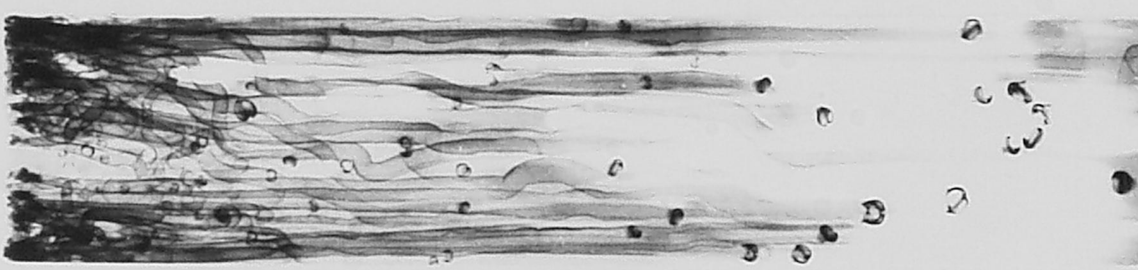

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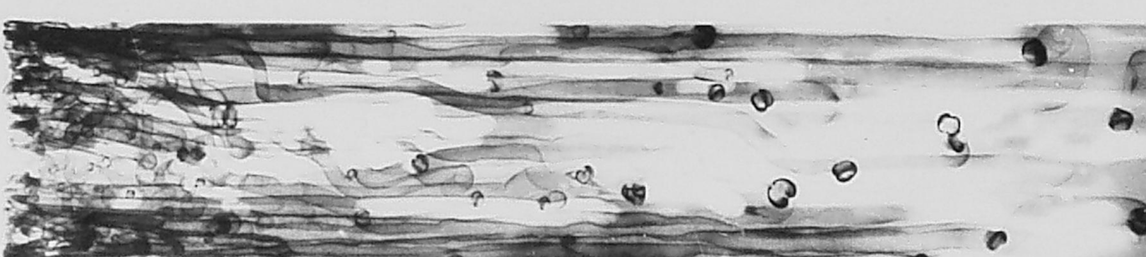

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Plate 3-A

Consecutive growth of shipworms, *Teredo navalis* Linnaeus at Naruto. Douglas fir test block (2 x 6 x 28 cm) was submerged in the sea on September 10, 1975.

1: One month after submergence.

2: Two months after submergence.

3: Three months after submergence.

4: Four months after submergence.

5: Five months after submergence.

Plate 3-A

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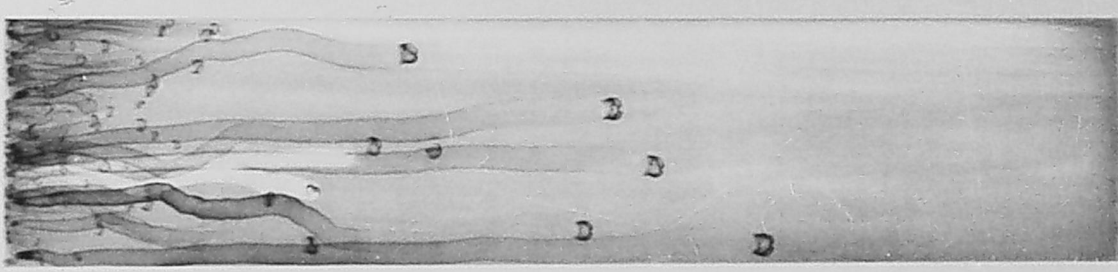

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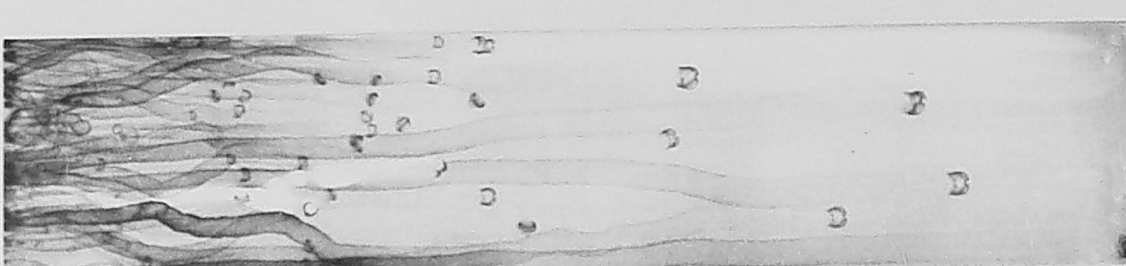

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Plate 3-B

Consecutive growth of shipworms, *Teredo navalis* Linnaeus at Naruto. Douglas fir test block (2 x 6 x 28 cm) was submerged in the sea on September 10, 1975.

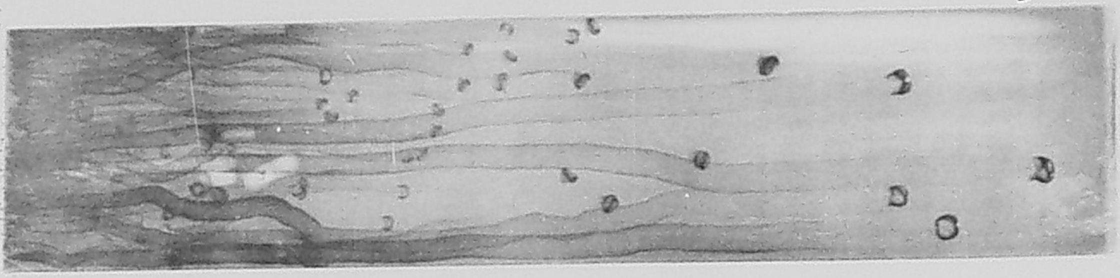
6: Six months after submergence.

7: Seven months after submergence.

8: Eight months after submergence.

9: Nine months after submergence.

10: Ten months after submergence.



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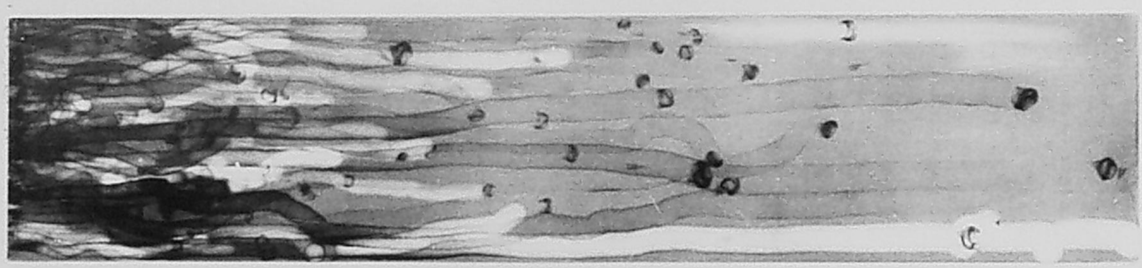

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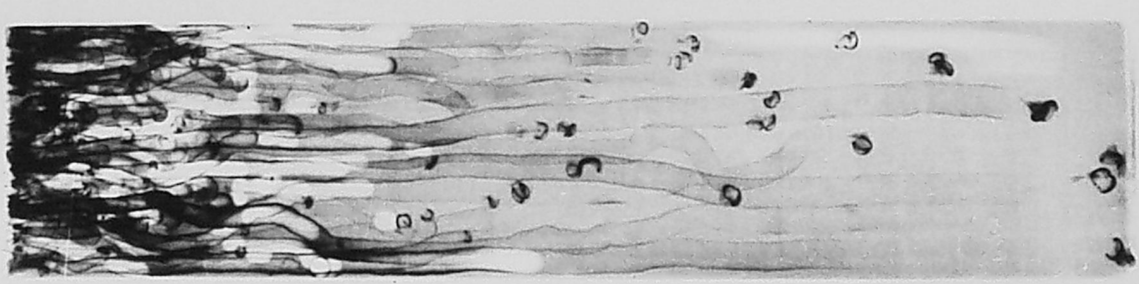

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V. Effect of the Time and the Length of Immersion on the Rates of Shipworm Attack on Wood

In practical problems of protection of wood against shipworm attack, the rates of attack -- variation of the extents of shipworm attack with the time and the length of immersion can be of great importance.

The number of shipworm tunnels (e.g. Mawatari, 1959) or weight loss (e.g. Kondo and Ishii, 1958) or area reduction (Okada and Sakai, 1958; Tsunoda and Nishimoto, 1972; Haderlie and Mellor, 1973) have been converted into a shipworm attack rating. Of these criteria, area reduction seems to be best if measurement can be done easily and accurately. However, the use of X-ray would be the most available when it is necessary to estimate the progress of attack with the length of immersing period (e.g. Crisp et al., 1953). Comparison of the reliability of the X-ray method with the visual assessment in which the number of burrows in cross section was counted showed a good correlation (Oliver, 1959). The reliability of the method was also demonstrated by Fougerousse (1968), Fougerousse and Deschamps (1968), Fougerousse and Lucas (1970, 1976), and Fougerousse and Gueneau (1971).

In the present investigations area reduction was measured and was discussed in relation to the time and the length of immersion.

V-1. Materials and Method

The investigations were conducted at Naruto and Takahama.

At Naruto a test string consisting of 3 western hemlock (<u>Tsuga heterophyra</u> Sargent) test blocks (4 x 4 cm in section and 30 cm in length) was submerged vertically from the floating experimental raft so that 3 test blocks might be respectively at 30, 80 and 130 cm below the water surface. The blocks were submerged for a month to 6 months at the longest during the period from June 1 to December 28, 1973 being coincided with the season of settlement at the test site (see part II).

After removal of the string, foulers and surface debris were washed off. And then the test blocks were dried before cutting 5 slices (1-3 mm in thickness) at intervals of about 5 cm from the end of each block for measuring the reduction of cross section caused by shipworm attack. The measuring device employed was an automatic area meter, Hayashi Denko AMM-5 Type, accurate to the nearest square millimeter. Therefore, the results were shown as the reduction of cross sectional area in percentage. Maximum limit of potential measurement was defined to 35 % since the slices could not be taken from heavily attacked blocks. Because the automatic area meter can be applied to the slices with thickness of 3 mm at thickest, the slices with over 35 % of cross-sectional area reduction mean that they were riddled too severely to be subjected to cutting into the slices thinner than 3 mm.

At Takahama test blocks were suspended at the test station B (see Fig. 8). The length of immersion of Scotch pine (<u>Pinus sylvestris</u> Linnaeus) test blocks, substituted for western hemlock used at Naruto, ranged from a month to 7 months during the periods from June 1 to December 28, 1975 and from June 1 to December 29, 1976. All other experimental procedures were the same as those at Naruto.

V-2. Results and Discussion

V-2-1. Investigation at Naruto

The extents of area reduction in percentage that are the average values of 3 test blocks removed at the same time are shown in Table 33.

Table 33. Percentage of cross-sectional area reduction of blocks and the number of borer apertures per 100 cm^2 * at Naruto during the period from June 1 to December 28, 1973.

Immersion date	Removal date: July 1	July31	Aug.30	Sep.29	Oct.29	Nov.28	Dec.28
June 1	1** (16)	4 (41)	15 (36)	22 (56)	21 (59)	35*** (47)	
July 1		1** (22)	7 (28)	12 (34)	14 (37)	30 (30)	
July31			1** (2)	1** (13)	1** (8)	Lost	
Aug.30				1** (67)	9 (125)	15 (80)	
Sep.29					1** (138)	25 (206)	
Oct.29						1** (29)	4 (37)
Nov.28							0 (1)

*: Number of borer apertures is shown in the brackets.

**: Below 1 %.

***: Above 35 %.

The rates of shipworm attack on wood blocks increased proportionally with the length of immersion, though the rates of increase varied with the season of submersion as shown in Fig. 16. The larger increase in monthly attack tended to occur in the 2nd and the 3rd months, which well corresponded with the results of growth rates discussed before (see part IV). However, the exceptions were observed for the test blocks which were submerged on June 1 and July 1: the highest extents of boring damage were found in the 6th and the 5th month respectively. No development of damage was noticed for the blocks immersed on July 31. The latter case is possibly explained by the scant occurrence of shipworms in August. Furthermore, the foulers' covering and the accumulation of debris on the surfaces would contribute to preventing the later shipworm settlement.

The more infestation of borers in the test blocks apparently resulted in the severer extent of attack as seen in the blocks submerged on September 29. Though the number of borer apertures is not the direct reliable measure of shipworm attack, the results show that the blocks submerged in a month with heavy shipworm infestation probably suffer more serious damage. Because the number of borer punctures on the wood surfaces is not likely to increase in proportion to the length of immersion period as can be seen in Table 33, the length and the time of immersion must be considered with caution to protect wood against shipworm attack.

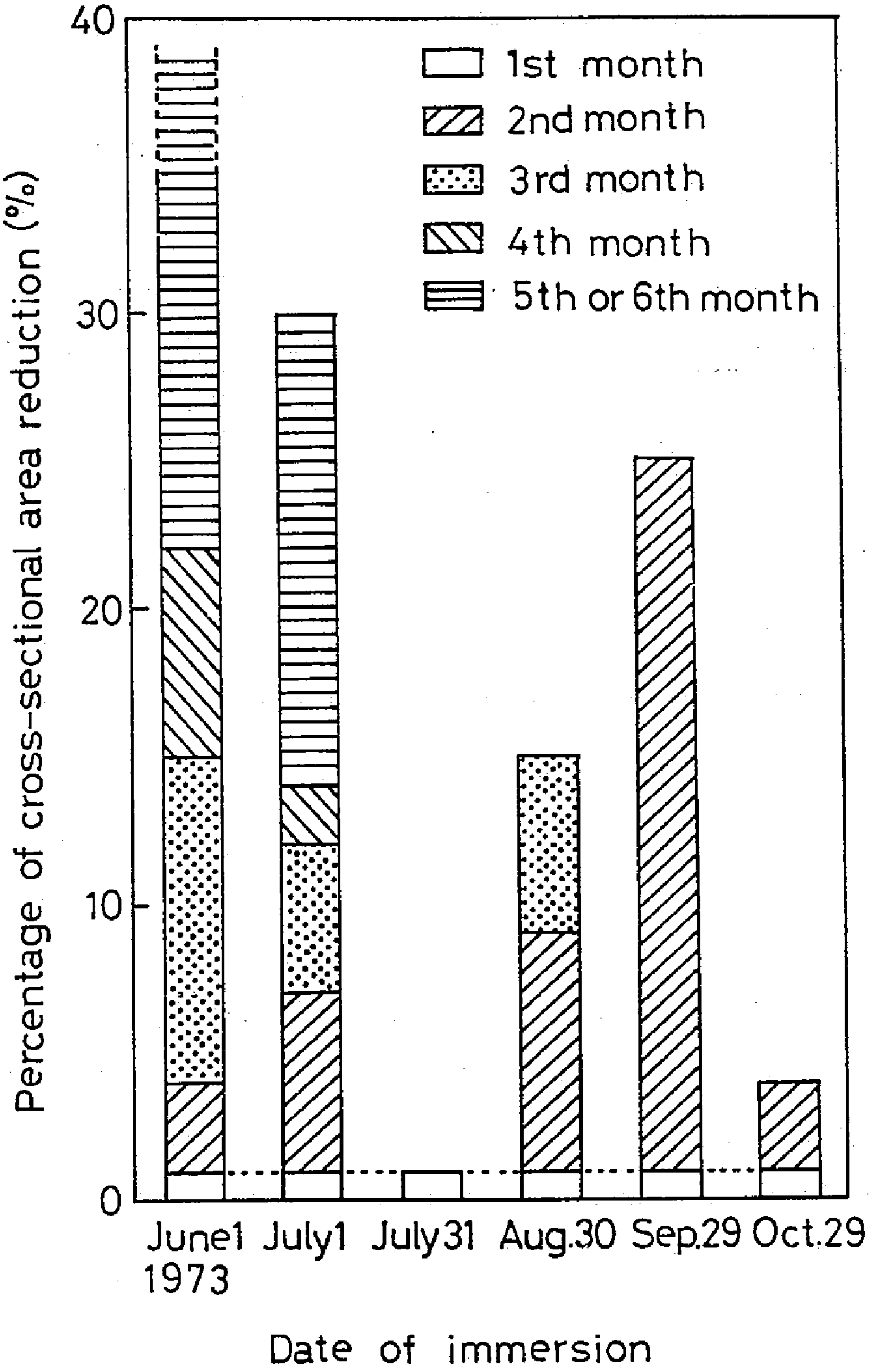


Fig. 16. Progress in the rates of shipworm attack on wood submerged at Naruto during the period from June 1 to December 28, 1973.

V-2-2. Investigation at Takahama

Table 34 shows the summarized results of the first series from June 1 to December 28, 1975.

Table 34. Percentage of cross-sectional area reduction of blocks* at Takahama during the period from June 1 to December 28, 1975.

Immersion date	Removal date July 1	Aug. 1	Sep. 1	Oct. 1	Nov. 1	Dec. 1	Dec. 28
June 1	1**	Lost	Lost	Lost	Lost	35***	35***
July 1		1**	Lost	Lost	Lost	35***	35***
Aug. 1			Lost	23	35***	35***	Lost
Sep. 1				1**	12	25	33
Oct. 1					0	3	15
Nov. 1						0	2
Dec. 1							0

*: Average value of 3 test blocks removed at the same time.

**: Below 1 %.

***: Above 35 %.

Many of the test blocks were unfortunately lost because testing area was visited by a typhoon in August.

The test blocks submerged on August 1 were riddled so seriously that the extent of attack reached over 35 % of cross-sectional area reduction until November 1. High water temperatures in the period distinctly conduced to the rapid destruction. As compared with the above example, the test blocks exposed on September 1 suffered the slightly lower boring damage with area reduction of below 1 % for a month, 12 % for 2 months, 25 % for 3 months and 33 % for 4 months. At Naruto the severest loss in cross section was recorded in the 2nd month for the blocks which were suspended in the peak of monthly shipworm settlement, October (see Table 33 and Fig. 16), whereas this trend was not noticeable at Takahama where the peak of monthly settlement was observed in September[1]. There is no satisfactory explanation for this difference found at separated localities.

From June 1 to December 29, 1976 the same series was conducted, and the results are shown in Table 35.

Table 35. Percentage of cross-sectional area reduction of blocks* at Takahama during the period from June 1 to December 29, 1976.

Immersion date	Removal date July 1	Aug. 1	Sep. 1	Oct. 1	Nov. 1	Dec. 1	Dec. 29
June 1	1**	1**	5	22	35***	Lost	Lost
July 1		1**	7	21	35***	35***	35***
Aug. 1			2	25	35***	35***	35***
Sep. 1				1**	1**	11	20
Oct. 1					0	1**	4
Nov. 1						0	0
Dec. 1							0

*: Average value of 3 test blocks removed at the same time.

**: Below 1 %.

***: Above 35 %.

1) In August the blocks were not recovered at the test station B but the heaviest settlement occurred in September judging from the results at the test stations A, C and D (see Table 23).

With the increase in the length of immersion, shipworm attack on wood blocks became more serious as similarly evidenced at Naruto. The 1st month of submersion generally did no conspicuous damage to the test blocks (see Table 33 and 35), but the exception was perceived in August, 1976, namely 2 % loss of cross section of blocks depending on the enormous settlement of shipworms in the month.

It is, moreover, noticeable that a marked monthly increment in the extent of shipworm attack was observed in September for the blocks submerged on June 1, July 1 and August 1 respectively falling on the 4th, the 3rd, and the 4th month period as shown in Fig. 17.

There is a widely accepted circulation among wood dealers that the logs stored in sea water get into dangerous condition if they have to be kept in the sea for a period longer than 45 days. The results on the rates of shipworm attack obtained at Naruto and Takahama demonstrated the above circulation is quite reasonable. The growth studies, which is described in part IV, also seem to support the circulation. Accordingly it is very important to avoid the longer storage of logs in sea water during the season of settlement of shipworms at given localities. Much attention should be paid to when the storage of logs sets in and how long the logs are stored in the sea, particularly significant if the storing duration includes August, September and October. In the case of storage which starts in November or December, it would be unnecessary to remove the logs from sea water onto the land even when they are stored for a longer period.

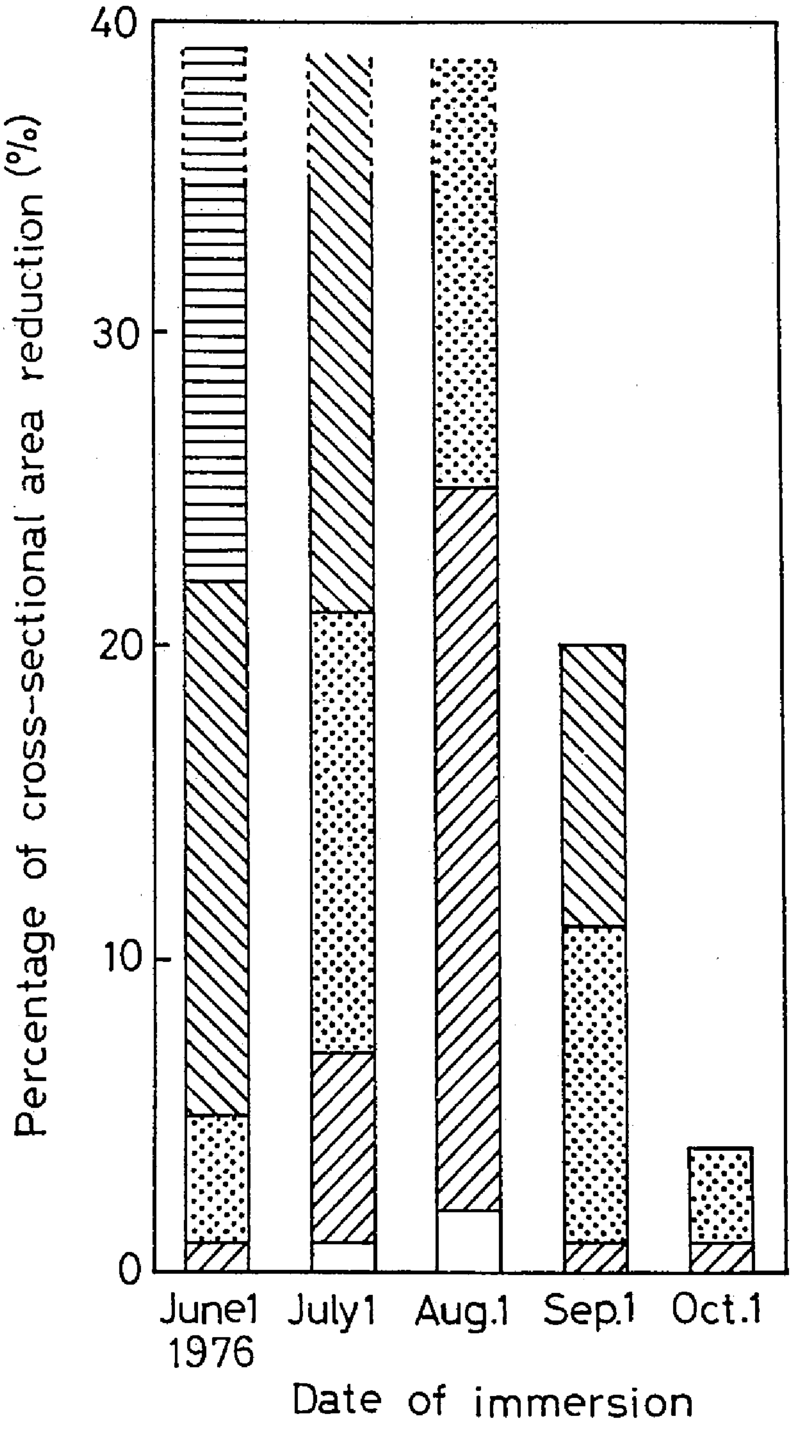
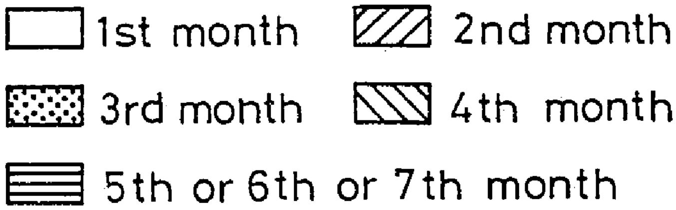


Fig. 17. Progress in the rates of shipworm attack on wood submerged at Takahama during the period from June 1 to December 29, 1976.



However, the presence of Bankia species deserves to be cautioned because prevailing incidence of the bankian borers seems to occur in the fall.

The logs are originally wrapped with bark except for cross ends, and the bark's covering gives natural effective protection against shipworm attack to the logs stored in the sea (e.g. M'Gonigle, 1925; Edmondson, 1955; Kramp, 1937; Nair, 1956; Tsunoda, 1972). Inconveniently, some logs are passively barked at felling, loading, unloading and operations before storage of them as a bundle raft or a flat raft in sea water. As a natural consequence, they are exposed to shipworm attack more readily than those with advantageous bark wrapping. The logs, in conclusion, should not be stored in sea water for a period longer than 2 months during the season of shipworm settlement, though the dangerous duration varies with localities: species present, numerical abundance of the animals and others.

V-3. Summary

The rates of shipworm attack on Scotch pine (Pinus sylvestris Linnaeus) test blocks (4 x 4 cm in section and 30 cm in length), which were expressed as the percentage loss in cross-sectional area of the blocks, generally increased proportionally with the length of immersion. At Naruto the blocks submerged on July 1, 1973 suffered below 1 % of cross-sectional area reduction for a month, 7 % for 2 months, 12 % for 3 months, 14 % for 4 months and 30 % for 5 months; at Takahama the blocks submerged on July 1, 1976 suffered below 1 % of cross-sectional area reduction for a month, 7 % for 2 months, 21 % for 3 months and over 35 % for 4 months. There found a few exceptions: no development of shipworm attack was recorded for the blocks submerged on July 31, 1973 at Naruto; very slow progression in boring damage for the blocks immersed on Oct. 1, 1976 at Takahama. Therefore, both the length and the time of immersion are important to determine the rates of shipworm attack on wood. The rapid development of shipworm attack was usually noticed in the 2nd and the 3rd months after immersion at Naruto. At Takahama September was the most dangerous month.

As the number of borer apertures on the wood surfaces did not seem to increase with the length of immersion, that cannot be the reliable measure of progress of shipworm attack. The heavier infestation of shipworms, however, obviously resulted in the severer boring damage as well demonstrated by growth studies.

In practical problem of protection of logs against shipworm attack, the logs should not be stored in sea water for a period longer than 2 months during the season of serious settlement of shipworms possibly from June to October.

Conclusions

The coasts of Japan are seriously infested with wood-boring bivalves belonging to family Teredinidae as evidenced in part I. The most important species in Japanese waters are *Teredo navalis* Linnaeus and *Lyrodus pedicellatus* (Quatrefages). *Bankia* species are occasionally found at some localities. Though the animals of genus *Bankia* are not abundant in number, they can be deserving of special caution because of the possibility of rapid growth.

Season of settlement of shipworms has been investigated at various localities in the world because the informations on the subject could give the first step to understand the shipworm problem. Shipworms breed for 7 months or so from June through December along the coasts of Japan (part II). At a few localities the settlement of shipworms is noticed even in January and extremely in February. The peak of settlement is observed in August or September or October varying with localities, which may be caused by the differences of species present, the fluctuations of water temperatures through the year, the amount of wood available for the borers, the activities of fouling communities and so forth. Consequently, in the sea water log storage areas the logs are exposed to shipworm attack for a relatively long period in some cases so that the time of removing logs onto the land before the damage is detected becomes a matter of importance.

The logs are generally stored in the form of a bundle raft or a flat raft in the zone between 0 m and 2 m below the surface of the water. However, shipworms tend to attack wood located all through the water column, and the intensity of settlement is definitely severer in deeper regions than in surface ones (part III). It is effective to remove not only floating riddled wood but also the sinkers at the bottom for the purpose of reducing and preventing the economic damage on the basis of the knowledge of settling season.

The shipworms, inconveniently to the logs stored in sea water, grow acceleratedly for the incipient few months just after initial boring. Based on the growth studies, the shipworms can lengthen their burrows up to over 5 cm within 2 months (part IV). The pace of growth is evidently influenced by environmental factors. Sudden and extreme change in the principal factors such as water temperature and salinity might result in the death of the animals, though the shipworms are known to be both eurythermal and euryhaline.

The fact that almost all the early attempts for preventing shipworm attack have been unsuccessful in practical use suggests that eradicating the adult borers in wood and the larvae is very difficult. Accordingly the most reliable way to protect logs against shipworm attack seems to land them within 60 days after the start of storage if the logs have to be stored in the season of serious settlement, particularly in July, August, September and October. The results on the rates of shipworm attack on wood also support the counterplan (part V). However, the logs are actually covered with bark which is expected to be a natural chemical and/or physical barrier. The propagation of fouling organisms and the accumulation of debris on the wood surfaces must counteract the settlement of shipworms and the growth of them. Therefore, the time of landing logs would be a little later in practical cases, if the data on the season of settlement, the rates of growth, and the rates of attack on wood permit the longer storage of logs in the sea at given localities.

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